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EDITORIAL NOTES.

OWING to pressure of original articles our Editorial Notes are this month considerably reduced in length.

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THE class list for the Second Part of the Natural Sciences Tripos, Cambridge, contains the names of two geologists who attained a first class: E. W. Ravenshear, M.C., M.A., Clare, and W. A. Macfadyen, B.A., St. John's. We believe these two gentlemen were the only geological candidates in the second part of the Tripos this year. The Harkness Scholarship is awarded to Mr. Ravenshear.

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MONSIEUR A. LACROIX, Member of the Institute and Professor of Mineralogy at the National Museum for Natural History, Paris, gave during the month of June four lectures at the Imperial College of Science (Royal School of Mines), South Kensington. The title of the course was announced as "Divers Modes de Dynamisme des Eruptions Volcaniques: Phénomènes de Lateritization". The lectures were delivered in French, and illustrated by numerous lantern slides. Sir Jethro J. H. Teall took the chair, and the course was attended by a considerable audience of petrologists and advanced students of geology.

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WE have received a copy of an interesting paper read by Dr. A. W. Rogers, F.R.S., to the Chemical, Metallurgical, and Mining Society of South Africa on the identification of the mineral character of particles in mine dust by the application of petrological methods. By an ingenious application of the well-known Becke bright-line method Dr. Rogers has been able to identify particles of quartz down to less than one micron in diameter. The importance of this is obvious, in view of the injurious properties of quartz dust in the air breathed by miners. In the discussion on this paper one speaker expressed surprise that any practical result should have followed consultation with a geologist. Now the fact is that geology is such a wide subject and deals with so many sides of science that there are few matters of a physical kind on which a geologist has not something to say, generally very much to the point. This was abundantly proved during the War.

ORIGINAL ARTICLES.

Differentiation and Ore-deposits.

By R. H. Rastall, M.A., F.G.S., University Lecturer in Economic Geology, Cambridge.

At the present time most mining geologists appear to be in general agreement on the principle that primary ore-deposits are derived from igneous magmas. Furthermore, it is now almost universally recognized that the segregation and concentration of the metals and their compounds into payable ore-deposits is but part of a larger and more fundamental problem, namely, the differentiation of the igneous rocks, a problem which has exercised the ingenuity of petrologists for many years past and is still by no means solved. Unfortunately most of the speculations and theories put forward in explanation of these phenomena are in the main founded on facts and inferences derived from the study of the silicates; comparatively few petrologists have taken into account the behaviour of the oxidic and sulphidic compounds of the useful metals, which are commonly regarded in the light of rare and accidental constituents of the magma, rather than as having any particular bearing on the point at issue. The most notable exception to this general statement is Vogt,[1] whose work on slags and ore-deposits is of an epoch-making character from the theoretical point of view, as well as of immense practical importance in smelting and blast-furnace practice. However, within the last few years great attention has been devoted by mining geologists to the subject of the genesis of ore-deposits, mainly because of its bearing on the question of persistence in depth or the replacement at lower levels of one ore by another, such as is known to occur in certain cases. It may be suggested, therefore, that the time has now come when it may be possible to attempt to combine the facts hitherto discovered along different lines of research into a coherent whole.

We have stated that most mining geologists are in agreement as to the derivation of primary ores from magmas, but there is still a good deal of difference of opinion as to the nature of the processes by which this derivation or segregation is brought about. The most unfortunate feature of the whole problem is that investigation by experiment is almost, if not quite, impossible; it is unlikely that we shall ever be able to realize in our laboratories the temperatures and pressures that must prevail at even small depths in the earth's crust, small, that is, by comparison with the radius, though large when expressed in feet or miles. It is necessary, therefore, to fall back on indirect evidence and arguments from analogy, and it must be admitted frankly that extrapolation is always a dangerous process.

[1] *Studier over Slagger*, Stockholm, 1884; *Die Silikatschmelzlösungen*, Kristiania, 1903–4.

As we have already stated, much difference of opinion has prevailed and still continues to prevail among petrologists as to the real nature of the processes by which differentiation of rock-magmas has been brought about. From our point of view the elucidation of the exact mechanism of the processes involved is of less importance than a clear recognition of the fact that differentiation has taken place. Here it is necessary to consider for a moment what we really mean by differentiation. As a matter of fact two distinct ideas are here involved, namely, (*a*) the production of heterogeneity within the limits of a single continuous mass, and (*b*) the splitting of an originally homogeneous mass into two or more separate and discrete portions.[1] It may be regarded as certain that both of these effects have been produced in different ways in different cases.

Theories of differentiation may be divided into three principal categories, as follows: (1) differentiation by sinking of crystals in a liquid magma, (2) differentiation by diffusion of molecules in solution to the marginal portions of a cooling and crystallizing mass, (3) separation of a solution into two immiscible fractions as temperature falls. It will be observed that (1) and (2) are very similar, while (3) is essentially different, in that its occurrence may be long antecedent to solidification. Hence we see that there are really two types of differentiation, one depending on solidification (crystallization), the other being entirely independent of it. Another point which has led to much discussion is this, whether any form of differentiation is dependent on assimilation of rock from the walls of the magma-basin. This hypothesis of the production of heterogeneous differentiation products by absorption of material acting as a flux has been largely developed by Loewinson-Lessing [2] and by Daly.[3] Both of these authors consider that there were two primary magmas, granitic and basaltic respectively, and Daly regards the alkaline rocks, the syenites and trachytes and their congeners, as formed by differentiation from the primary granitic magma after assimilation of limestone. To this process he applies the name *syntexis*. Neither author has apparently considered the origin of the two primary magmas from a still earlier common source, a possibility which must also be taken into account in a complete theory.

It will, I think, be generally agreed that in a case of this kind the best method of procedure is to start from a foundation of known facts and work back to the unknown. Let us, therefore, begin with

[1] It has been well pointed out by Daly that the formation of crystals of different minerals, such as quartz, felspar, and mica, from a magmatic solution is in reality a process of differentiation in its simplest form. Each single crystal is in such a case a unit of differentiation. This point has been ignored by most petrologists. It is in reality only the mono-mineralic rocks which can be regarded as strictly homogeneous, and these are very rare.

[2] Loewinson-Lessing, GEOL. MAG., 1911, p. 248.

[3] Daly, *Igneous Rocks and their Origin*, New York, 1914.

a simple case on which we possess some solid information as a basis. In the smelting of metals from their ores the metal sinks to the bottom, while the non-metallic impurities and fluxes rise to the top as a slag. This is not merely sinking by gravity, but depends on the principle of immiscible liquids. Vogt has shown that at any given temperature above the freezing-point of both liquids there is a certain amount of mutual solution, the metal dissolving some of the slag and the slag dissolving some of the metal, and that the solubility in each fraction increases with the temperature. It may be inferred, therefore, that at a certain very high temperature there would be complete mutual solubility in any proportions. Such temperatures have not, however, been attained in ordinary furnace practice. Now, if we invert the argument and imagine a rock-magma consisting of mutually dissolved silicates and sulphides at a very high temperature, but constantly losing heat by conduction, a time will come when the magma must begin to separate into two layers, one rich in silicates, the other in sulphides, and the sulphide portion being the heavier will occupy a lower position, thus leading to a segregation of sulphides at the bottom of the magma basin. In other instances the metals may be present as oxides or fluorides, instead of sulphides, but the result will be the same, namely, a stratification of the magma. It is possible that in some cases the metallic compounds may be lighter than the silicates, and therefore form the upper layer, but the principle is the same. The amount of one of the constituents present in the rock formed from the other fraction when solidified, e.g. the amount of sulphide in normal gabbro or norite, will depend on the solubility of the sulphide in the gabbro magma at its temperature of consolidation. Therefore, it would appear that there must be a limit to the percentage of primary ore that can occur evenly disseminated throughout a rock mass. If the amount of metal was originally in excess of this proportion it would necessarily form a richer segregation layer at the bottom. The foregoing statement represents what must occur in the simplest possible case. When the metals form volatile compounds the relations are more complex, as will be explained in a later section.

The argument may now be carried one stage further back. It has been suggested by certain leading petrologists that some of the phenomena of differentiation, as shown by the distribution of varying rock-types in definite areas, can be explained on the supposition of limited miscibility between magmas of different silica percentage, or in other words between acid and basic magmas. The general idea is that with a falling temperature the silicates of magnesia, iron, and lime become less soluble in the silicates of alumina, potash, and soda, and a separation occurs, the silica dividing itself in the proper ratio between the two fractions, thus producing two partial magmas. The magnesia, iron, and lime require less silica for complete normal saturation than the alumina, potash, and soda, hence one fraction is a basic magma, the other an acid one, in the ordinary

sense. The basic magma is of higher density and therefore sinks to the lower level.

With regard to the metallic constituents, sulphides and oxides, it is evident that they will tend to distribute themselves also between the two partial magmas in the ratios of their solubilities. From the association of particular metals with definite rock-types it may be concluded that some metals are more soluble in the acid fraction, some in the basic, while others appear to occur in both. Thus, copper and iron, for example, are found in igneous rocks of almost all types, tin, tungsten, and molybdenum are definitely associated with granites, while nickel, chromium, and platinum belong to basic and ultrabasic types. When the temperature falls still further a similar process will take place with regard to the metallic constituents dissolved in each partial magma, and the oxidic and sulphidic ores will separate out in each case as immiscible layers, as before outlined.

Now it is clear that this principle is capable of almost indefinite extension ; when the temperature is high enough we may conclude that all substances, whether silicates, sulphides, oxides, fluorides, borides, tungstates, or anything else, may become mutually soluble, i.e. miscible in all proportions, therefore the deeper we descend into the earth the more generalized should we expect the rock-types to become, and the more evenly distributed the metallic compounds. It is obvious, however, that the lowest levels attainable by artificial means or the depth of formation of most deep-seated rocks brought up by geological disturbances of mountain-building and faulting, are but trifling in comparison with the radius of the earth.

It may be objected that the known varieties of igneous rocks are too numerous and complicated to have been formed in this simple way, but it has been effectively shown by Daly [1] that by far the greater number of rock-types are rare and local, forming but a minute fraction of the total. For example, he shows that in North America the much-talked-of alkaline group (syenites, etc.) constitute only about 0·1 per cent of the total, and in other parts of the world they are not much more abundant.[1] In fact, it can be maintained, probably with truth, that the vast majority of the rock-types to which special names have been applied are due to local circumstances, such as assimilation of limestone and similar fluxing material, giving rise to special and peculiar chemical and physical processes within the magmas. Daly considers that there are but two fundamental magmas, the granitic and the basaltic, and of these he is inclined to regard the basic or basaltic magma as the most primitive. This is in conformity with the high density of the earth as a whole.

We therefore picture the evolution of the primitive homogeneous earth-magma as a process of differential splitting into successive fractions owing to a progressive decrease of mutual solubility with fall of temperature. The exact nature of the process giving rise to

[1] R. A. Daly, *Igneous Rocks and their Origin*, New York, 1914, p. 47.

the splitting is a matter of minor importance; the facts of nature and the distribution of the varying rock-types are in themselves sufficient proof that something of the sort must have occurred, however it was brought about. It is unnecessary here to consider in detail the means by which the differential fractions have become isolated in separate basins within the earth's crust, or poured out as extrusions at the surface (lava-flows). This part of the subject has been discussed in detail by many writers. What we are mainly concerned with now is the ultimate fate of the metallic constituents that were dissolved in the differentiated partial magmas before solidification began.

Let us first consider the case of a granite magma, such as the granites of Cornwall, into which has been carried during partition a considerable proportion of tin, tungsten, copper, arsenic, lead, zinc, and other metals, together with fluorine, boron, and water, in addition to the constituents of the silicates, felspar, and mica, together with an excess of silica. The micas crystallize first, followed by the felspars, in the order of their freezing-points; these are followed by quartz, the metallic constituents, together with the fluorine, boron, and water, all tending to concentrate in the last unfrozen residue, presumably in the middle and lower parts of the mass, which are the hottest. All these probably remain unsolidified to a comparatively low temperature, perhaps below a visible red heat, although it must be remembered that pressure raises freezing-points. However, the already solidified mass is still cooling and therefore shrinking in volume. Consequently cracks must be developed to relieve the strain. These cracks apparently often extended radially into the surrounding rocks. Along these cracks the still fluid material from the interior must shoot out, under high pressure due to superheated water, filling them with the residual magmatic material, and in the process also bringing about far-reaching chemical changes in the wall-rock of the fissures. Thus we account for the pegmatites, aplites, and greisens, so common in and around many highly mineralized granites. In some cases also the escape of fluids from the cooling magma has been facilitated by earth movements, inducing fissure systems dependent on the direction of these movements, rather than merely radial. Sometimes the active chemical agents derived from the magma bring about the most far-reaching changes, such as tourmalinization, in the granite itself, the extreme case being schorl-rock, where everything has been converted to quartz and tourmaline; in other instances topaz is very abundant.

But the point of immediate interest is the fate of the metallic compounds in the magma. We know from incontrovertible evidence that the deposition of the ores belongs to the later stages of magmatic cooling. There is no need to labour this point. It may be taken as demonstrated that the deposition of the ores is subsequent to the crystallization of the main mass, and many of them are found in the pegmatites and greisens, having been deposited

contemporaneously with their formation. But the question of the quartz-veins in the stricter sense of the word requires a little more detailed consideration. In the first place it should be remembered that the processes here under review take place at temperatures above the critical point of water, 365 degrees C., and therefore the usual distinction between liquid and vapour is then non-existent. For this reason the term fluid has been used throughout this discussion. We do not know the temperatures at which the normal quartz-felspar pegmatites actually solidify, but we do know that they often contain ore-minerals. Some ore-minerals therefore form at fairly high temperatures. There is now abundant evidence from observation that many true pegmatites pass by insensible transitions, by diminution of felspar, mica, etc., and corresponding increase of quartz, into quartz-veins in the ordinary sense of the term, either with or without metallic minerals. In some cases a vein may be a pegmatite within the granite, passing gradually into a quartz vein in the sediments. It is clear, therefore, that there is no real distinction between these two types.

It is necessary next to inquire why some of the constituents of the original magma should remain liquid so much longer, i.e. to a lower temperature than the main mass. The answer to this question is to be found in a consideration of the effect of the more volatile substances contained in the original magma. As this gradually solidifies it is obvious that all the substances of lowest freezing-point must tend to concentrate in the last fluid residue. Among these substances are to be reckoned compounds of the useful metals. These probably exist in the magma as fluorides, borides, sulphides, and hydrates. The presence of superheated water here is doubtless of first-class importance, as shown by Arrhenius.[1] For example, tungsten fluoride is known to be a gas at the ordinary temperature, while tin fluoride boils at 705 degrees C.[2] As the temperature falls these elements group themselves differently and eventually crystallize out as metallic minerals, together with the silica of the residual magma, which crystallizes as one of the two forms of quartz. The last fraction of all is a pure, or nearly pure, solution of silica, which forms the simple quartz-veins often found far from the margin of any visible intrusion. It appears clear, therefore, that there is no real line of demarcation between the so-called pegmatitic and hydrothermal mineral deposits.

When several metals are present in one individual magma, as is usually the case, each will form a compound having its own solidification temperature and therefore capable of travelling only as far as the corresponding temperature extends into the surrounding rocks; we shall therefore have a series of ore-zones around the intrusion, as is so well seen in Cornwall.

[1] "Zur Physik des Vulkanismus": Geol. Foren. Forh., vol. xxii, 1900, 395. Abstract in GEOL. MAG., 1907, p. 173.

[2] Roscoe & Schorlemmer, *Treatise on Chemistry*, vol. ii, 1913, pp. 861, 1095.

Thus it is obvious that when a partial magma has reached its final resting-place and is there crystallizing, there must be a more or less complete separation of metallic constituents. This takes place in two stages, first a concentration in the last residue of the crystallizing magma, and then a translation along with this residue into dykes, veins, and lodes.

This process is best known and the relations are most clear in the case of the acid magmas, but the same thing occurs in the case of basic intrusions, with one important difference. The basic magma is less rich in volatile constituents, fluorine and boron being absent, and for some reason not yet understood water is apparently less abundant. Hence there is less tendency for the metals to segregate into dykes and veins. More commonly they remain more or less evenly disseminated like chromium and platinum, or sink to the bottom like the nickeliferous sulphides. It is worth noting that chromium and platinum are most abundant in the ultrabasic peridotites, which are themselves to be regarded as differentiates of the larger basic magmas.

We are thus led to recognize two distinct types of ore-deposits of direct magmatic origin, formed by differentiation, namely, the segregations within the mass of the magma itself, such as the nickeliferous sulphides of Sudbury or the iron-ores of Kirunavaara, where there has been only separation by sinking within the basin, and secondly, the fissure deposits, dykes, and veins, formed by translation of metalliferous portions, usually upwards or laterally, and frequently extending beyond the boundaries of the basin; the clearest examples of this type are afforded by the tin and tungsten deposits, while a similar origin may be postulated for a great number of other metallic ores, including copper, lead, zinc, arsenic, antimony, bismuth, mercury, silver, and gold. It appears probable that as a result of extended study it will become possible to draw up further generalizations, by assigning each metal or group of metals to its own petrographic rock-type. Thus it appears that gold is specially characteristic of the monzonite group, while the rare earths are concentrated into highly alkaline partial magmas.

With regard to the actual mechanism of differentiation, the subject of so much discussion of late years among petrologists, the matter is of minor importance; it is the effects with which we are really concerned. All the facts go to show that some sort of splitting of magmas must have occurred; the question of how or why is mainly of academic interest. The chief battle at present is between the advocates of differentiation by diffusion *before* formation of solid crystals, and differentiation by gravity *after* the crystals are formed, while the immiscible liquid theory comes in a bad third. Now it is obvious that partial magmas which are still liquid after the differentiation cannot have been formed by sinking of solid crystals, or, at any rate, both fractions cannot. The upper fraction might, of course, become impoverished in certain constituents by sinking

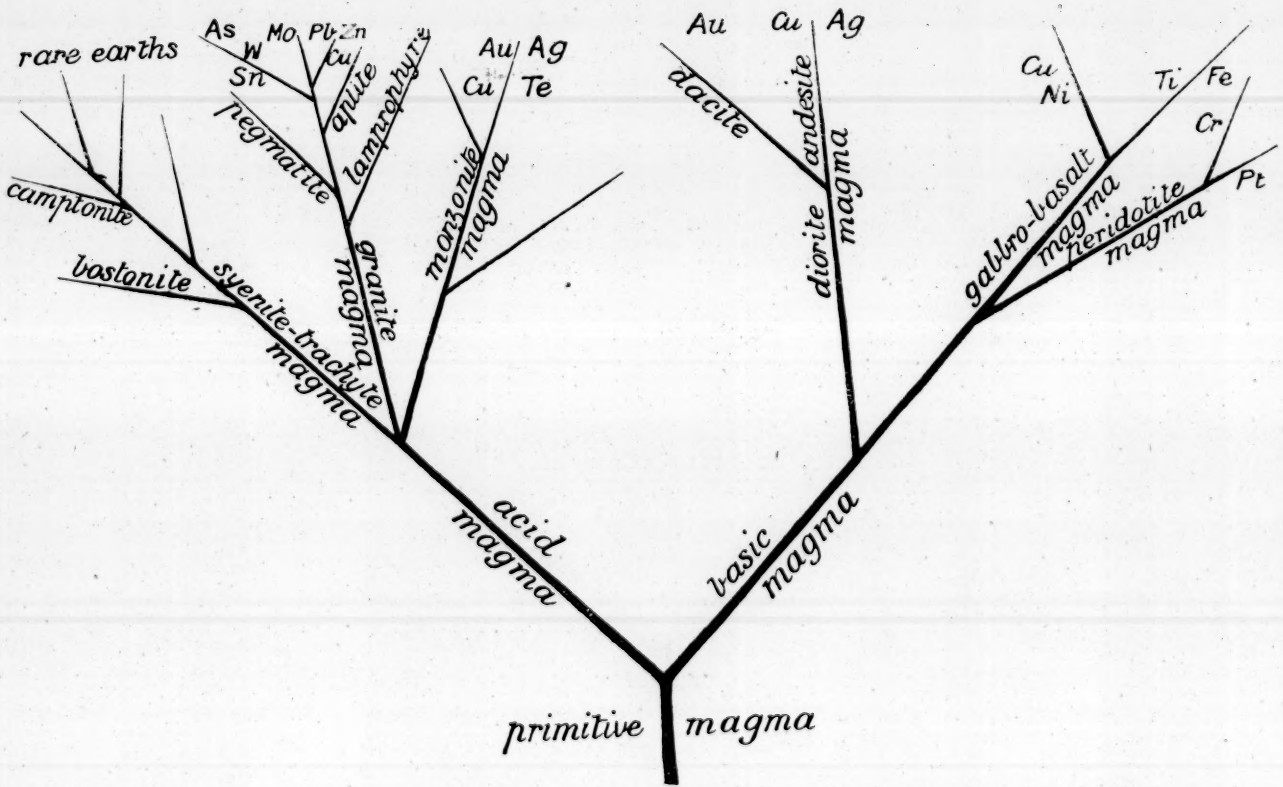
of crystals, but not the lower. Now there is evidence that during their final crystallization some intrusions have become stratified by gravitational sinking, as in the Palisade Traps of New York and New Jersey, where the lower layers are very rich in olivine and other heavy basic silicates, while the upper part of the sheet has almost the composition of a granite, and yet there are no lines of demarcation, but a gradual transition throughout.

On the other hand, there is evidence that metallic compounds tend to accumulate in the upper portions of granitic masses. In the great granitic bathyliths of Western America it has been described how the mineralization is concentrated in the upper portions of the minor domes or cupolas that diversify the general surface of the intrusion;[1] this is obviously due to a gravitational rising of the metalliferous fluids into the upper portions of the granite. It is immaterial whether this occurred before or after the general solidification of the rock.

Hitherto we have spoken mainly of ore-deposits occurring in definite dykes and veins or of segregations within or at the base of igneous masses. There yet remain other important classes, such as the brecciated lodes and the endless varieties of so-called contact and replacement deposits. It is not proposed to discuss at length the genesis of these. The lode-deposits of the type here indicated can be explained on essentially similar principles: vapours or solutions differentiated from igneous magmas penetrate into zones or belts of fractured rock, of the type commonly now described as "shatter belts". Various more or less far-reaching chemical changes were induced in the minerals of the country rock, while the constituents of the solutions were deposited as ore and gangue minerals in the interstitial spaces. Such lode-deposits often show no definite boundaries, but shade off gradually into the unaltered country rock. On the other hand, most of the replacement and contact deposits come under the petrological category of metasomatism, a special type of metamorphism involving a change in the total bulk-composition of the rock. This is a large subject, needing extended treatment, which cannot be followed further at this time. The point to be emphasized, however, is this, that the fluids giving rise to these types of lode-formation, contact, and replacement deposits are of the same nature and origin as those that have filled the sharply defined metalliferous veins, all being derived from igneous magmas. Of course, it is not here maintained that *all* ore-deposits are of direct igneous origin; doubtless there are many exceptions, but the evidence at present available goes to show that a vast number are so. Also no account is here taken of the highly important changes induced by oxidation, leaching, and secondary deposition. Only primary unoxidized ores are specifically referred to.

In the accompanying diagram an attempt is made to

[1] Butler, *Econ. Geol.*, vol. x, 1915, pp. 101–22.



Genealogical tree of the differentiated ore-deposits.

summarize in a graphic form the ideas here put forward and to construct a genealogical tree of the igneous rocks and their related ore-deposits, tracing their descent by successive steps from a hypothetical primitive magma, through various stages of differentiation to the innumerable and varied types that we see to-day. This must be regarded, however, as merely an attempt, and must not be taken too literally, since the data available are as yet insufficient for dogmatism on many points. As already stated the whole question of the actual physical mechanism of differentiation is still *sub judice*; between the diverse opinions expressed by eminent authorities it is as yet too early to decide. The fact remains that some sort of splitting of rock-solutions must have occurred; that is not disputed by any one, but it is improbable that we shall ever be in a position to state exactly what has happened in every case. Nevertheless, it is clear that these processes, whatever they were, have been the dominant factor in the origin and primary distribution of the deposits of the useful metals on which so much of the world's industrial development depends.

Notes on the Fauna of the Lower Devonian Beds of Torquay.

By F. R. Cowper Reed, Sc.D., F.G.S.

Part I.

(PLATE IV.)

Introductory Remarks.

OUR knowledge of the fauna contained in the Lower Devonian beds of England is extremely imperfect and unsatisfactory, partly owing to the scantiness of the material which has been collected, and partly to the poor preservation of most of the fossils themselves. The lists of genera and species given in the Survey memoir (Explan. Sheet 350) dealing with the Torquay district are not extensive, and in many cases the determination of the species or even the genera is open to doubt. Correlation in detail with the well-established and richly fossiliferous Lower Devonian of the Continent is almost impossible in such circumstances, but Kayser in 1889, on the strength of the palæontological evidence which he obtained on the spot, correlated the beds at Meadfoot with the Lower Coblenzian.[1] The fossils which he collected and identified from this locality were the following Rhenish species: *Zaphrentis oolitica, Rhynchonella daleidensis, Chonetes sarcinulata, Spirifera hysterica, Sp. paradoxa, Strophomena* cf. *Murchisoni, Pterinea costata.*

Classification of the Lower Devonian Beds of Torquay.

The division of the Lower Devonian of the Torquay district into a lower portion termed the "Meadfoot Beds" and an upper portion

[1] Kayser, Neues Jahrb. f. Min. Geol., 1889, i, p. 188.

termed the "Staddon Grits" is adopted in the Geological Survey memoir (Explan. Sheet 350, 1903), the basal group of the Lower Devonian, the "Dartmouth Slates", being considered to be unrepresented there. The boundary between the Meadfoot Beds and Staddon Grits is not satisfactorily fixed, but the two principal exposures which have yielded most of the fossils here described are respectively near Kilmorie House, in Meadfoot Bay, and in the New Cut, on the Lincombe Drive. The lithological characters of the beds at these two localities as well as the contained faunas are sufficiently distinct. The red fossiliferous beds at Smugglers' Cove differ somewhat in lithological characters from those of the New Cut, and contain a different assemblage of fossils, so far as the scanty fauna is known, but they are ascribed to the Staddon Grits in the above-mentioned memoir of the Geological Survey.

Undoubtedly there is much scope for further systematic collecting of fossils from these beds, and though the specimens are as a rule poorly preserved or fragmentary, yet they frequently admit of specific identification when studied alongside of better material from the Continent.

The collections in the Sedgwick Museum, Cambridge, have supplied most of the specimens on which the following notes are based, but the Lower Devonian fossils in the Torquay Museum, the Jermyn Street Museum, and the British Museum have also been examined, and my thanks are due to Mr. Harford Lowe, Dr. Kitchin, and others for much assistance in my work.

Previous Literature.

A large number of fossils were described or recorded by Phillips in his *Palæozoic Fossils of Cornwall and Devon* (1841) from "Meadsfoot" or "Meadsfoot Sands", but only in some cases (marked * in the following list) have the original specimens been traced, and with regard to the remainder of the types some doubt exists. The names following in brackets are those used in the present article.

**Pleurodictyum problematicum* Goldf.
**Nucula ovata* Sow. (= *Cleidophorus subovatus* sp. nov.).
**Avicula anisota* Phill. (= *Pterinea anisota*).
**Orthis sordida* Phill. (= *Chonetes plebeia* Schnur).
O. plicata Sow. 1840 (not *O. plicata* Sow., Davidson, Mon. Brit. Foss. Brach., iii, p. 245).
O. granulosa Phill. (genus doubtful).
Spirifera costata Sow. (?, = *S. subcuspidatus*).
Euomphalus serpens Phill.
**Bellerophon trilobatus* Sow. (= *Bucaniella* sp.).
Orthoceras tentaculare Phill.
**Homalonotus* sp. (? = *H. armatus* Burm. ?).

Etheridge, sen., in 1867 [1] recorded the following Lower Devonian species from South Devon, but whether all came from the Torquay district is uncertain, as is also the accuracy of the identifications.

[1] Etheridge, Quart. Journ. Geol. Soc., vol. xxiii, 1867, pp. 579, 619–25, 636.

Aviculopecten polytrichus Phill.
Pterinea anisota Phill.
Clidophorus ovatus Sow. (= *C. suboratus* sp. nov.).
Athyris concentrica v. Buch.
Leptæna laticosta Conr. (= *Trop. rhenanus* Frech).
Orthis granulosa Phill.
Orthis (?) *hipparionyx* Vanux.
Rhynchonella cuboides Sow.
Homalonotus Herscheli Murch. (?).
H. armatus Burm.

Tawney[1] in 1870 gave a list of fossils from the "red grits" of Smugglers' Cove. *Tentaculites scalaris* is said to be most abundant, and the following species are also recorded :—

Cypricardia lamellosa (?).
Pterinea ventricosa (?).
,, (like *bifida* or *anisota*).
Orthis arcuata (?).
,, (like *Berthoisi*).
Streptorhynchus gigas.
Homalonotus (like *Johannis*).

Several other molluscan genera are mentioned without specific names, but the whole list is characterized by uncertainty as to the identifications. Davidson[2] in his monograph mentions only the following brachiopods from the Lower Devonian rocks of Meadfoot, nearly all his recorded and figured species coming from the North Devon beds of this age.

Spirifera undifera.
,, ,, var. *undulata*.
Rhynchonella cuboides (Sow.).
Leptæna laticosta Conr.

In 1881 Woodward[3] published a list of fossils (determined by Etheridge) from the Red Beds of New Cut, in connexion with his description of the species *Homalonotus Champernownei*, but only three of them were specifically identified (*Rhynchonella pengellyana* ? *Streptorhynchus umbraculum*, and *Pleurodictyum problematicum*), the others having only generic names assigned to them. It is of interest to note that *Cyrtoceras* and *Orthoceras* are given in the list, for cephalopods seem as a rule extremely rare in this district.

In 1882 Etheridge[4] described and figured several species from New Cut and Smugglers' Cove, and thus added considerably to our knowledge of the fauna, though the present author is inclined to differ from some of his determinations in the light of further material.

Cypricardia lævisulcus Ether. (= *Tellinites lævisulcus*).
Modiolopsis sp.
Spirifera cultrijugata Röm. (?) (= *Orthis provulraria* Maur.).
Rhynchonella laticosta Dav. (?) (? = *Tropid. rhenanus* Frech).
Orthis hipparionix vel *O. striatula* (= *O. provulraria* Maur.).
Chonetes sordida (Phil.) (= *Ch. plebeia* Schnur).
Loxonema (?) sp.

[1] Tawney, Rep. Devon Assoc., vol. iv, pt. i, 1870, p. 291.
[2] Davidson, Mon. Brit. Foss. Brach., vol. iii, Devonian (*passim*).
[3] Woodward, Geol. Mag., 1881, pp. 489, 528, Pl. XIII.
[4] Etheridge, ibid., 1882, p. 154, pl. iv.

Woodward [1] at the same time described and figured a new species, *Homalonotus goniopygæus*, from Smugglers' Cove, and a pygidium which he attributed to *H. Champernownei*.

In 1901 Whidborne [2] described some supposed Lower Devonian fossils from the site of the Pengelly Memorial Hall, Torquay, but Messrs. Jukes-Browne and R. B. Newton [3] subsequently disputed the accuracy of his determinations and regarded the fauna as indicating Middle Devonian beds. With the latter conclusion the present author is compelled to agree.

Note.—In the following descriptions of the species the letter S. denotes that the specimen is in the Sedgwick Museum, while the letters M.P.G. and T. respectively indicate the Jermyn Street Museum and the Torquay Museum. The index numbers following these letters refer to the individual specimens or tablets in the collections.

CRUSTACEA.

Genus HOMALONOTUS.

Homalonotus (*Digonus*) *goniopygæus* Woodward.

1882. *Homalonotus goniopygæus* Woodward, GEOL. MAG., p. 157, Pl IV, Fig. 1, ? 2.

1918. *Homalonotus* (*Digonus*) *goniopygæus* Reed, GEOL. MAG., pp. 317, 324.

The original specimen, consisting of a pygidium, which is in the Sedgwick Museum, was described by Dr. Woodward as follows: "The axis is very broad in proportion to the lateral portions, and the division between them is but slight. Breadth of axis at proximal border 6 lines. It is composed of from 12–13 annuli or coalesced caudal rings, the corrugations of which are slightly bent downwards on each side and continued to the border of the pygidium as well-developed side-ribs. The costæ diminish in size and strength from the proximal border, till they disappear near the hinder part of the axis about 4½ lines from the extremity, which is smooth or nearly so. There are no spines or other ornamentation on the surface of the specimen."

A few additional remarks may here be made on this pygidium. It has an elongated, triangular shape, but its lateral edges are hidden by matrix, and its tip is slightly broken. The convexity of the general surface is gentle at the proximal end, but increases somewhat towards the tip. The sides of the pygidium converge at first at an angle of about 45 degrees, but behind the pleuræ the rate of tapering of the pygidium is rather slower. There are only 11–12 distinct rings on the axis, the posterior fifth part of the axis having the narrow rings only faintly marked, and finally becoming obsolete. The axis is very greatly convex in front, and tapers rapidly, but becomes more convex and tapers more slowly towards its indistinct tip, which forms a blunt point circumscribed by a weak furrow, and

[1] Woodward, ibid., 1882, p. 157, Pl. IV, Figs. 1–3.
[2] Whidborne, ibid., 1901, pp. 533–40, Pl. XVIII.
[3] Jukes-Browne & Newton, ibid., 1914, pp. 311–18.

2

3

1

4

E. M. King, del.

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NEW LOWER DEVONIAN HOMALONOTI.

does not reach the end of the pygidium. There are only eight pleuræ on the lateral lobes, and of these the first six plainly correspond with axial rings; but the narrow posterior part of the lateral lobes appears to be smooth and unfurrowed. The pleuræ are nearly straight, and are directed gently backwards at increasingly acute angles to the sides of the axis. The axial furrows are very weakly impressed. The general surface of the axis and pleuræ is covered with closely set small hollow tubercles.

Woodward believed that this pygidium resembled most nearly *H. Knighti* König, from the Ludlow, but the present author [1] has referred it to the subgenus *Digonus*, for its relations seem to be with *H. scabrosus* Koch [2] and *H. rhenanus* Koch,[3] but especially with *H. crassicauda* Sandb.,[4] as Kayser in his appendix to Koch's paper (op. cit., p. 152) has suggested. To this same group probably belongs *H. Vanuxemi* Hall,[5] of the North American Lower Devonian.

Dimensions.—"Length 12 lines; breadth at proximal border 11 lines" (Woodward, op. cit.).

Horizon.—Lower Devonian (Staddon Grits).

Locality.—Smugglers' Cove, Torquay (S. 87).

Homalonotus (*Burmeisterella*) *bifurcatus* sp.nov. (Pl. IV, Figs. 1–3.)

1918. *Homalonotus* (*Burmeisterella*) *bifurcatus* Reed, Geol. Mag., pp. 315, 325.

Definition.—Body elongated oval, gently convex from side to side. Head-shield broadly subtriangular, narrowing anteriorly to form a short truncate upturned snout (prora); genal angles rounded. Glabella subrhomboidal, widening slightly towards base, about one and a half times as long as wide, subtruncate anteriorly, completely circumscribed, bearing three longitudinal rows of tubercles (or spine-bases) of three tubercles in each row, and one outer pair of tubercles, the posterior tubercles being in all cases the largest, and the tubercles of the two lateral rows arranged in pairs; but the tubercles of the median row and of the outer pair alternate with the lateral ones and are smaller in size. Axial furrows shallow but distinct, converging to level of eyes, but anteriorly subparallel and uniting in front of glabella. Occipital ring broad, rounded, well defined by continuous occipital furrow arched forward rather suddenly in middle of base of glabella; pleuro-occipital portions with traces of small tubercle near axial furrows. Facial sutures having their posterior branches arched sharply outwards behind the eyes and cutting the lateral borders of the head-shield in front of the genal angles; anterior branches in front of eyes running

[1] Reed, Geol. Mag., 1918, pp. 317, 324.

[2] Koch, Abh. k. preuss. geol. Landesanst., iv, 2, 1883, p. 43 [115], t. iii, figs. 8–10; t. ix.

[3] Ibid., p. 32 [104], t. iii, figs. 1–6.

[4] Ibid., p. 39 [111], t. v, figs. 1–5.

[5] Hall, Palæont. New York, vol. iii, 1859, p. 352, pl. lxxiii, figs. 9–13; Hall and Clarke, ibid., vol. vii, 1887, p. 11, pl. Vb; Clarke, Mem. 9, New York State Mus., pt. ii, 1909, p. 95, pl. xxii, figs. 2–6.

forwards at first with a slight convergence, but then rather suddenly bending inwards to traverse the pre-glabellar region and unite in a short median point, thus conjointly forming a distinct transverse suture, which defines the prora posteriorly. Epistomal (= rostral) sutures arising from the points at which the facial sutures bend inwards, and forming a pair of short subparallel sutures bounding the prora laterally, and cutting the anterior margin of the head-shield at right angles. Epistomal (= rostral) plate situated on lower surface of head-shield, subtriangular in shape, bearing a stout median apiculus, and bounded by the inferior continuation of the epistomal sutures, which cut it off from the flattened triangular lateral portions of the doublure. Cheeks with general surface convex and elevated. Free cheeks, with inner portion swollen and rising to maximum height at eyes, having large rounded boss or tubercle situated towards margin slightly in front of eyes; margin simple, without definite border. Eyes small, situated rather close to the glabella on elevated portion of cheeks at level of second lateral glabellar tubercles. Thorax of 13 segments, strongly convex. Axis broad, gently convex, faintly marked off from pleural portions. Axial rings bearing two pairs of tubercles, of which the outer ones are the larger. Pleuræ arched down on each side, gently flattened, particularly towards extremities, which are obtusely rounded and slightly curved forwards. Twelfth pleura bearing large rounded boss at half its length, but absent from eleventh and thirteenth pleuræ. [Anterior thoracic segments not sufficiently preserved for determination of characters.] Pygidium elongated, semi-elliptical in shape, with simple lateral margins, but furnished posteriorly with a short bifurcated spinose process. Axis long, conical, convex, slowly tapering, composed of eleven complete rings, with traces of one or two more very faintly indicated rings followed by a short non-annulated terminal portion with a blunt tip nearly touching base of posterior forked process. Axial rings well defined, some bearing tubercles, i.e. four tubercles on the first ring like those on the last axial ring of the thorax, two faint ones on the second ring, and two distinct ones on the third and fourth rings, apparently corresponding with the outer ones of the first ring; the fifth ring has two smaller ones, apparently corresponding with the inner pair; the sixth ring has none; the seventh ring has the two outer ones; the eighth to tenth rings have only faint traces of one outer pair; the eleventh has one more distinct pair. Axial furrows strong, distinct. Lateral lobes arched gently down on each side, with smooth undefined narrow border. Seven or eight distinct flattened pleuræ on each side, nearly straight, but with the ends slightly curved, not reaching margin, and with traces of a large low boss or tubercle on first pleuræ at about two-thirds its length and of a more distinct one on the fourth pleura at about half its length. Posterior end of pygidium furnished with a pair of closely placed, slightly diverging curved spines arising from a common

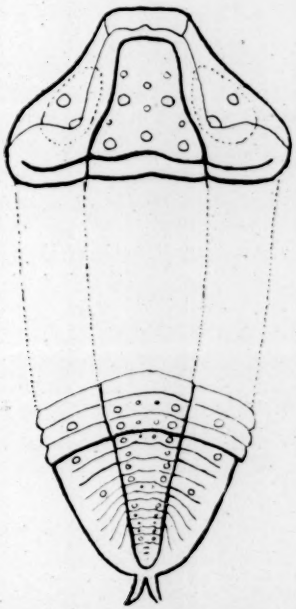
base, horizontally extended, and about one-sixth the length of the pygidium. Surface of shell ornamented with small distant granules.

Dimensions.—(The specimen is laterally compressed and distorted.)

		mm.
Length of head-shield (actual)	about	40
Width of head-shield (actual)	,,	40
Length of glabella	,,	30
Width of glabella at base	,,	21
Length of pygidium (actual) to base of spines	,,	33
Width of pygidium (actual)	,,	44
Width of axis of pygidium (actual) at front end	,,	15
Length of terminal spines	,,	6

Horizon.—Red Beds (Staddon Grits).

Locality.—New Cut, above Meadfoot Bay, Torquay. Sedgwick Museum (S. 88) (S. 6).



Remarks.—The material on which this new species *H. bifurcatus* is founded consists of the laterally compressed and somewhat obliquely distorted cast and internal impression of a nearly complete individual (S. 88). All the parts of the body are in their natural position, except the head-shield, which has been bent back under the body and thus broken off from the thorax, but it is only slightly displaced from its proper position of attachment. The internal cast of the head-shield therefore points backwards in the specimen, and is attached to the impression of the thorax and pygidium. There is also the impression of part of the doublure and epistomal plate of the same head-shield, but the cast of these parts is not preserved.

The thorax is not well exhibited, being crushed and hidden by matrix, but the last three or four segments are sufficiently perfect to show the tubercles on the axis and the nodes on the pleuræ. The pygidium is nearly complete, though distorted; the right lateral lobe is almost uninjured; the axis exhibits its characters well in the cast and impression, and the bifurcated terminal spine shows distinctly on the left side of the impression, but the cast has the posterior end of the pygidium broken off.

There is also a portion of a large pygidium from the same locality in the Sedgwick Museum (S. 6), which is represented by the internal cast and the external impression, and may belong to the same species. This specimen has its axis, measuring over 30 mm. in width, at its front end, but only four rings are preserved. Of these the first and third rings bear two pairs of tubercles, of which the outer ones are the larger; the second ring only possesses one pair corresponding to the outer ones, and the fourth ring only the inner pair.

With regard to the relations of this species, we must first notice the close resemblance of the pygidium to that of *H. elongatus*, Salter,[1] from the Lower Devonian of Meadfoot, but the forked mucro at its extremity is peculiar, and recalls the species from the Rhine described by Koch[2] as *H. aculeatus*, though in his figure this special feature is not represented. It may be remarked that a similar peculiar bifurcated termination of the pygidium is present in some American species of *Dalmanites* (*Odontocephalus*) from the Devonian (e.g. *D. selenurus* Eaton[3] and *D. bifidus* Hall[4]). The head-shield and thorax of *H. Champernownei* Woodw.[5] appear to possess nearly the same characters as our new species, particularly in the tuberculation of the head-shield, but the anterior margin, prora, and course of the transverse suture are not known in the imperfectly preserved type-specimen which was figured by Woodward, and the pygidium appears to be different in its axial characters, and certainly lacks the posterior forked termination. The axial rings of the thorax are also stated to bear only one pair of tubercles instead of two pairs. The head-shields of *H. armatus* Burm.[6] and *H. subarmatus* Koch,[7] so far as they are known, seem allied to *H. bifurcatus*, especially in their tuberculation, but the pygidia are different.

[1] Salter, Mon. Brit. Trilob., p. 122, pl. x, figs. 1–2.
[2] Koch, op. cit., p. 93, t. i, fig. 7.
[3] Hall, Palæont. New York, vol. vii, 1888, p. 49, pl. xiB, figs. 15–21.
[4] Ibid., p. 53, pl. xiB, figs. 22–5.
[5] Woodward, Geol. Mag., 1881, p. 489, Pl. XIII.
[6] Koch, op. cit., p. 84, t. i, figs. 1–4, and p. 151.
[7] Frech, Leth. Palæoz., Bd. ii, 1897–1902, p. 218, text-figure.

(*To be continued.*)

Hornblendite at Vavasour Mine, Cantley, Quebec.

By J. Stansfield.

(By permission of the Directing Geologist, Geological Survey of Canada.)

THE interesting rock-type hornblendite occurs at the Vavasour Mine, though it has only a very small development. It covers an area of about 600 square feet and is cut by two of the apatite-mica veins, which are so numerous at this locality. The rock was incorrectly marked amphibolite on the map in Guide Book 3, International Geological Congress, xii, 1913, facing p. 112.

In the hand specimen it is coarsely crystalline and shiny black by reason of the excellent cleavage of the hornblende. The only minerals seen in the hand-specimen in addition to hornblende are pyrite and an occasional speck or veinlet of a greenish mineral. Under the microscope, in addition to the green or greenish-brown hornblende there is seen a small amount of a scapolite of low birefringence, a phlogopite mica, a little sphene, and a grain or two of black iron-ore. Augite within one of the crystals of hornblende appears to indicate the relation of the rock to the gabbro of the remainder of the hill, and the probable close genetic connexion of the hornblende with augite.

The chemical composition of the rock is given below:—

SiO_2	42·21
Al_2O_3	16·32
Fe_2O_3	3·79
FeO	7·49
CaO	11·01
MgO	12·00
Na_2O	3·67
K_2O	2·67
CO_2	·72
H_2O	·45
S	·22
	100·55

On an Exposure of Sands and Gravels containing Marine Shells at Easington, Co. Durham.

By David Woolacott, D.Sc., F.G.S.

THE purposes of this short paper are to place on record and to bring to the notice of geologists a deposit of sands and gravels containing numerous marine shells which is exposed on the Durham coast north of Easington. Marine shells (*Littorina*, *Cyprina*, etc.) have been collected before from sands and gravels lying above sea-level on this coast,[1] but the deposits containing them have usually

[1] Shells were collected at Marsden by Howse and others at 100–50 feet, and also at Cleadon at 100 feet. I have collected shell fragments of *Littorina*, *Cyprina*, and *Cardium* and one whole specimen of *Littorina* from the Cleadon Sand Pit at 100 feet, and numerous entire specimens of *Littorina littorea* and fragments of *Cyprina* from sands and gravels in Fulwell Quarries

been removed in the course of quarrying operations, and no collection of shells has been preserved in any museum; it is therefore of interest that a deposit has lately been observed which can be examined at any time by geologists, and from which specimens of shells can easily be obtained. It is also of importance that the exact mode of origin of these particular deposits should be determined.

The exposure here noticed occurs in the cliff on the south-east flank of Beacon Hill, about half a mile north of Easington station, which is on the N.E.R. coast line midway between Sunderland and Hartlepool. It can be examined in a steep footpath (the top of which is marked by a stile) leading down to the shore at this point. The deposit occurs at an elevation of about 60 feet, and consists of horizontally and regularly bedded sands and gravels which rest on a level shelf of Magnesian Limestone, and which are distinctly traceable for a considerable distance to the north and south. The gravels can be seen in the railway cutting behind for at least 30 feet above the level of the shelf. The pebbles consist mainly of water-worn fragments of Magnesian Limestone, but others of quartz, sandstone, quartzite, rhyolite (Lake District), and Cheviot porphyrite occur. It is, therefore, late Glacial or post-Glacial in origin.

Many of the pebbles are bored by annelids (*Polydora*) and others by *Saxicava*. In the case of the latter some of the shells are still in their holes. The sands and gravels are full of large and small, whole and broken shells, some of which are in an excellent state of preservation. The species include *Littorina littorea*, *L. obtusata*, *Patella vulgaris*, *Purpura lapillus*, *Mytilus edulis*, *Cyprina islandica*, *Saxicava*, *Pecten*. Several foraminifera have been proved to occur in the sand. In one part of the deposit some *Helix* are cemented in, and Dr. Trechmann informs me that in the conglomerate a little further south many rodents' bones occur.

This deposit is of special interest as it is undoubtedly of the same origin as other sands and gravels which occur 12 miles to the north in Durham (their connexion can, indeed, be traced), and which can be proved up to 150 feet above sea-level. Howse described some caves at Marsden at this height in 1879, which he said were sea-caves, and associated the sands and gravels on these hills with their formation,[1] Kirkby noticed sands and gravels at Fulwell resting

at 150 feet. Trechmann has collected broken fragments of *Mactra*, *Turritella*, and *Cyprina islandica* from the Sheraton Kaims, which are about 4 miles inland at an elevation of 400 feet, and I have collected shell-fragments from the spreads of sand and gravel at Salton Piercy, near Hartlepool. It is, however, important to disconnect clearly the shell-bearing deposits which are found lying along the Durham coast up to 150 feet from the shell-bearing gravels and sands of the Kaims, and the spreads of sand and gravel which are associated with them.

[1] "Old Sea-caves and Sea-beach at Whitburn": Nat. Hist. Trans. Northumberland, Durham, and Newcastle, vol. vii, 1880, p. 361.

on rock against a terrace, which he describes as water-worn,[1] and Lebour states that the deposits on Cleadon Hills is a typical example of a raised beach.[2] I have described both the deposits at Cleadon and Fulwell, and from the evidence obtained regarded them as raised beaches.[3] At the latter place the sands and gravels were banked up against a buried terrace and contained at one point a large number of whole specimens of *Littorina littorea*. (The buried rock-terrace appeared to be water-worn and to have been cut by the agent that deposited the gravels.) The sands and gravels at Marsden are mapped as raised beaches on the Geological Survey maps of the district.[4] Lamplugh, Wright, and some Yorkshire geologists have doubted that these deposits are of direct marine origin, chiefly because no raised beaches occur in Yorkshire, and Dr. Trechmann states he is unable to see the necessity of assuming these gravel-deposits to be of marine origin.[5] The shells collected from these deposits have been referred to as having been obtained from kitchen middens.[6] At Kelsea Hill, near Hull, gravels and sands containing numerous marine shells (some of which are similar to those occurring on the Durham coast) can be proved to have been transported inland for some miles by ice from the bed of the North Sea. Since collecting in the Easington deposit I have re-examined the Kelsea Hill deposit, and have been struck by the similarity of the fauna and the mode of preservation of the shells and by the occurrence in both deposits of bored rocks with *Saxicava* in place, etc.; but have been impressed by the dissimilarity in their mode of occurrence.

The horizontally and regularly bedded gravels at Easington seem to have been deposited on the platform on which they lie, and this level shelf would appear to have been cut by wave action when the deposit was formed. This formation has, indeed, all the characters of a true raised beach, but it is possible that these may be deceptive. After my re-examination of the Kelsea Hill deposit I admit this possibility. I am, however, not convinced that the evidence obtained from an examination of the deposit is sufficient to prove that it is not an uplifted sea-beach.

If it is not of direct marine origin two other methods of formation are possible. It may be material carried by ice from the bed of the North Sea and deposited above sea-level. (There would appear

[1] *Geologist*, 1860, p. 294.

[2] *Geology of Northumberland and Durham*, p. 19.

[3] Nat. Hist. Trans. Northumberland, etc., 1900, and Univ. Durham Phil. Soc. Trans., 1907; Quart. Journ. Geol. Soc., vol. lxi, 1905, and *Geog. Journ.*, July, 1907.

[4] *Geog. Journ.*, July, 1907, p. 56.

[5] Quart. Journ. Geol. Soc., vol. lxxi, pt. i, 1915, p. 75.

[6] It is peculiar that a kitchen midden occurs on Fulwell Hills about 20 feet above the highest point at which these gravels occur. The suggestion that the shells in these deposits were from a kitchen midden is shown, by the nature of the deposit at Easington and also by the fragments that can be got from almost any exposure, to have been nonsense.

to be two ways in which this could have been done. It could either have been pushed inland by the ice and deposited at a higher level,[1] or there is the possibility of it being lifted up from the bed of the sea and carried forward as suggested by Debenham.[2]) Its regularly bedded and undisturbed nature and its extent are entirely against the idea that it has been carried by ice and dumped down in the place in which it occurs. On the other hand, the evidence is certainly in favour of it having been deposited in place by water; indeed, it would appear to have been formed as a marginal deposit. The other possible mode of formation is, therefore, that it was formed on the edge of a glacier-lake held up by ice lying off the Durham coast near the end of the Glacial Period, and that it thus consists of glacial material carried inland and afterwards re-assorted by water on the margin of an ice-dammed lake. The unbroken nature of the shells and their variety are strongly against this view.[3] No transported glacial material from the bed of the North Sea with such a varied fauna is known to exist in Durham.[4] From the Sheraton Kaims, which occur a few miles to the south and are about 4 miles inland at an elevation of 400 feet, Dr. Trechmann, after careful searching, has only been able to collect some very broken fragments of *Cyprina islandica*, *Mactra*, and *Turritella*[5]; yet in this deposit whole well-preserved shells of *Littorina*, *Patella*, *Saxicava*, and *Purpura* occur.

This deposit and the associated sands and gravels on the Durham coast are therefore of special interest. If they are raised beaches they obviously raise a peculiar question regarding the nature of the uplift that produced them, and if they are not they show how deceptive the evidence obtained from the mode of occurrence of deposits may often be, and they suggest a query regarding the extent of the glacier-lake of which they are the marginal deposits. All geologists to whom I have shown the sands and gravels at Easington, including some who doubted the existence of raised beaches on the Durham coast, regard them as being of direct margin origin, or admit that the deposit is masquerading as an uplifted marginal marine formation. Certainly geologists who described these superficial deposits on the Durham coast as raised beaches would appear to have been justified. Now that a fairly complete record of the glacial deposits of this coast has been worked out it appears of importance that the mode of origin of these particular formations should be determined. They can be much more clearly examined at

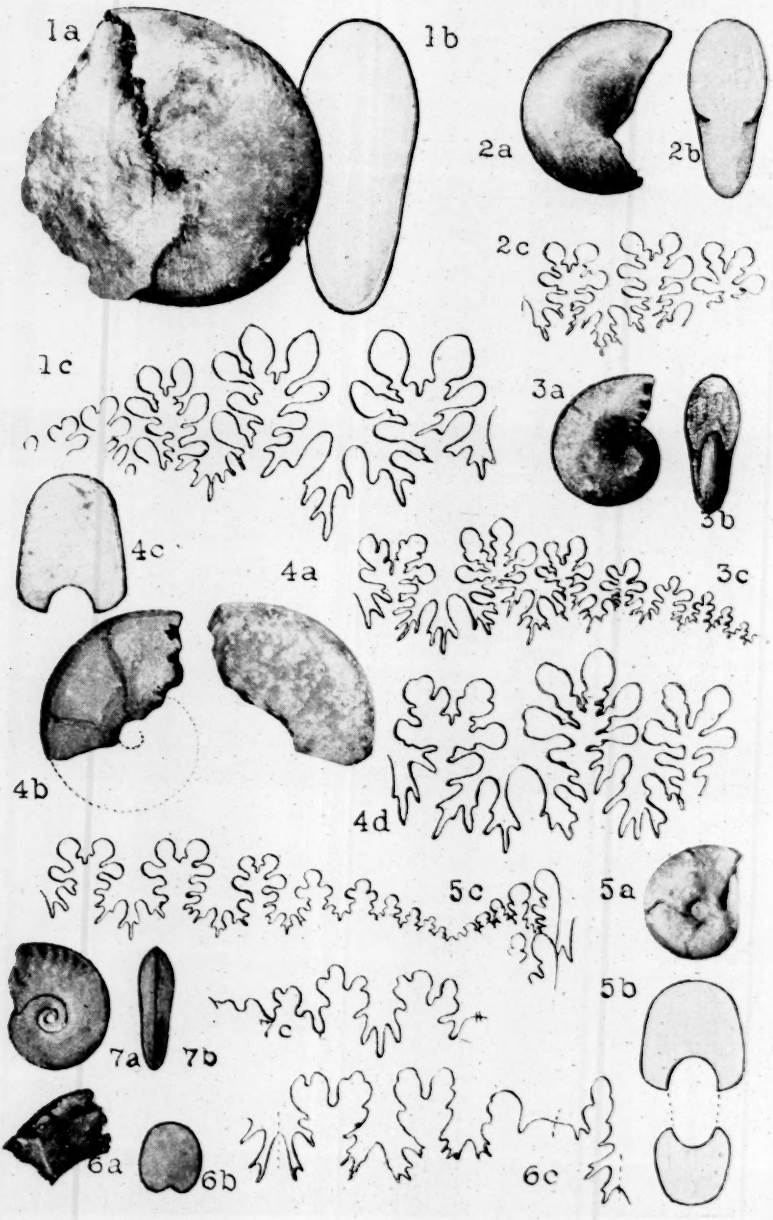
[1] Deposits have been observed raised from the sea bed in Spitsbergen by Garwood, Gregory, and Lamplugh.

[2] Quart. Journ. Geol. Soc., vol. lxxv, 1920.

[3] It is admitted that shell-bearing gravels have been transported inland in County Durham. The question at issue is whether there has been an uplift of the coastal area of Durham since Glacial times.

[4] I have not seen any *Patella* in place on the rock shelf, although some appeared to have been attached to the large pebbles in the gravel.

[5] Quart. Journ. Geol. Soc., vol. lxxi, 1915, p. 74.



J. W. G. phot., L. F. S. del.

JURASSIC AMMONITES FROM EAST AFRICA.

To face p. 511.

Easington than at any other point, and a thorough examination of this deposit should finally settle the question as to whether raised beaches do occur on the coast of north-east England. I should be glad to give any further particulars to any geologists who may desire to examine this deposit, and if it can be arranged should be pleased to accompany them to the exposure. Any expression of opinion regarding the mode of origin of this deposit after it has been examined would be welcomed. I have placed a collection of shells from it in the Sunderland Museum, and have also given some specimens to the Curator of the Hancock Museum, Newcastle.

On Jurassic Ammonites from East Africa, collected by Prof. J. W. Gregory

By L. F. Spath, B.Sc., F.G.S.

(PLATE V.)

THE small but very interesting collection of Ammonites described in the following pages was obtained during the summer of 1919 by Professor J. W. Gregory, to whom the writer is indebted for permission to study them. There are seven specimens altogether, three of them fragmentary, and all probably originally pyritized, but now converted into limonite. Though immature or fragmentary, all the specimens were seen to have indications of suture-lines, so that their study promised definite results even if, at first sight, it was difficult to place the fauna in the geological sequence. Superficially, there was greater resemblance to the Lower Cretaceous fauna (with *Phylloceras* of the *heterophyllum* group and *Lytoceras quadrisulcatum*) described from East Africa by Krenkel[1] than to the Sequanian fauna of Mombasa, recorded by Dacqué,[2] and a large series of which is preserved in the British Museum (Nat. Hist.).

On closer investigation, however, and after preparation of the suture-lines, it became evident that the age of the Ammonites corresponded with the presumed stratigraphical position of the beds which yielded them, namely "Bathonian, or post-Bathonian, but pre-Sequanian". Professor Gregory adds (in litt.) that the Ammonite beds [limestones and shales] are separated from the fossiliferous Sequanian by a considerable thickness of strata. The corals of the limestone immediately underlying the Ammonite-bearing beds, according to Professor Gregory, are not of the same genera as the known Bathonian corals of East Africa. Also they are not the same species as those of the Bathonian of Kutch, and Professor Gregory was at first disposed to put them as post-Bathonian. On the other

[1] "Die Untere Kreide von Deutsch-Ostafrika": Beitr. Pal. Geol. Ost.-Ung., vol. xxiii, pt. iv, 1910, pp. 201–50, 4 plates.

[2] "Dogger und Malm aus Ostafrika": ib., vol. xxiii, pt. i, 1910, pp. 1–63, 6 plates.

hand, Mr. R. B. Newton compared one of the molluscs to a species from the Bathonian of Abyssinia.

It was, therefore, of interest to obtain, if possible, more exact information from a study of the Ammonites, however few and fragmentary these were, and the writer is of opinion that the evidence points to a probable Bathonian [1] age of the Ammonite fauna.

DESCRIPTION OF AMMONITES

Genus PHYLLOCERAS, Suess.

Phylloceras aff. *Kudernatschi* Hauer, sp. (Pl. V, Figs. 1*a–c*.)

1852. *A. heterophyllus* (Sowerby), var., Kudernatsch, "Amm. Swinitza": Abh. k.k. R. A. Vienna, vol. i, pt. ii, p. 6, pl. i, figs. 5–9.
1854. *A. Kudernatschi* Hauer, "Beitr. Kenntn. Heterophyll. Ost. Mon.": Sitz.-Ber. Akad. Wiss., vol. xii, pt. iv, p. 902.
1860. *A. Kudernatschi* (Hauer), Ooster, Cat. Ceph. Foss., pt. iv, p. 72, pl. xvii, figs. 9–11.
1871. *Phylloceras Kudernatschi* (Hauer), Neumayr, Jurastud. (3), "Phyllocer. Dogger & Malm": Jb. k.k. R.A., vol. xxi, Hft. iii, p. 310, pl. xii, figs. 4–5.
1877. ,, ,, (Hauer), Gemmellaro, "Sopra alcuni Fossili della zona con *Posidonomya alpina*, Gras. di Sicilia": Faune Giur. & Lias., p. 128, pl. xviii, figs. 3–4.
1890. ,, ,, (Hauer), Jüssen, "Beitr. Kentn. Klaus-Schicht. N. Alp": Jb. k.k. R.A., vol. xl, p. 387, pl. ii, fig. 1.
1892. ,, ,, (Hauer), Neumayr & Uhlig, "Üb. v. Abich i. Kaukasusgesamm. Jura-Fossil.": Denkschr. Akad. Wiss. M. Naturw. Cl., vol. lix, p. 33.
1897. ,, ,, (Hauer), Hochstetter, "Die Klippe v. St. Veit b. Wien": Jb. k.k. R.A., vol. xlvii, pt. i, p. 141.
1905. ,, ,, (Hauer), Popovici-Hatzeg, "Les Céph. Jurass. Mt. Strunga": Mém. Soc. Géol. France, vol. xiii, fasc. 3, p. 10, pl. i, figs. 1–4.

Dimensions.—

Diameter	39 mm.	
Height of the last whorl	60	per cent of the diameter.
Thickness	38	,, ,, ,,
Umbilicus	5	,, ,, ,,

Description.—This ammonite is a typical *Phylloceras*, with almost closed umbilicus and an elliptical section with evenly rounded sides. The specimen is not perfect, however, the shell not being continued into the mass of limonite shown in Fig. 1*a*. Also, since the specimen is septate throughout, it only represents the inner whorls of a larger ammonite. The test is somewhat imperfectly preserved, and shows fine, radial striation at the anterior portion, but near the end of the shell the ornament is greatly worn. Even here, however, the fine

[1] The zone of *Macrocephalites macrocephalus* (Cornbrash) should be included in the Bathonian, and the Callovian considered to begin with the zone of *Proplanulites Koenigi*. This is contrary to Continental usage; but the (English) type successions should be adhered to.

spiral lines along the periphery, forming a peculiar feature of the test in this specimen, still persist. The extremely fine radial lines describe a strong forward curve on the inner third of the lateral area, bend back again towards the outer third, and near the periphery once more swing gently forward, after the style of the ornament in Popovici-Hatzeg's good photographs. Though the ornament is worn, some of the costæ are more prominent than others, and it seems probable that the ornament was that typical of *Phylloceras Kudernatschi*. It also appears that the test consisted of four layers, as in *Phylloceras. Malayanum* G. Böhm, described by both the author of that species[1] and by Dacqué,[2] namely a smooth inner layer, a weakly costate second layer, followed by the lineate third layer with its peculiar string- or tube-like costæ, easily detached and preserved (in the specimen under examination) only in one or two places. The fourth (smooth) outer layer of the test is absent. The ventral area is slightly compressed as in the section given by Jüssen,[3] yet regularly rounded; and the greatest thickness of the whorl is about midway between the periphery and the umbilicus. The latter is very narrow, funnel-like, and very deep, with the sides regularly rounding into it.

The suture-line could not be exposed plainly enough for complete delineation, but apart from the six saddles shown in Fig. 1*c* (drawn at a diameter of about 30 mm.) there are probably two or three more monophyllic saddles on the umbilical slope. The external saddle is very distinctly diphyllic, the first lateral saddle tetraphyllic, and the following three saddles diphyllic again.

Observations.—The small umbilicus and linear ornament of this specimen, together with the absence of constrictions, characterize it as a member of the *heterophyllum* group of the genus *Phylloceras*, which group ranges from the Lower Lias up into the Cretaceous. Its general shape and suture-line seem to agree very well with *Phylloceras Kudernatschi* (Hauer). According to Neumayr, Gemmellaro, and Jüssen, the umbilicus of that species amounts to 7 per cent of the diameter, whereas the figures given by Popovici-Hatzeg show a smaller umbilicus, comparable with that of the present specimen. There also is some variation in the whorl-shape. Kudernatsch's type (pl. i, figs. 5 and 6) shows the greatest thickness near the middle of the whorl, whereas his smaller specimen (figs. 8 and 9) and the ammonite figured by Neumayr have the region of greatest thickness nearer the umbilicus. On the other hand, the excellent photographs given by Popovici-Hatzeg show a laterally flattened whorl. Apart from the slightly larger umbilicus of Jüssen's figure (not in agreement with that of Fig. 1*a*, and therefore probably drawn too open) the section given by that author best

[1] "Beitr. Geol. Nied. Ind.": *Palæontographica*, Supp., vol. iv, pt. i, 3. "Oxford v. Wai Galo," 1907, pl. xiv, figs. 4*b*, 5.
[2] Op. cit., 1910, pp. 6, 7, pl. i, figs. 1–3.
[3] Op. cit., 1890, pl. ii, fig. 1*b*.

agrees with the whorl-outline of the specimen here described. In Neumayr's figure of *Phylloceras Kudernatschi* the ventral area is truncated; but this flattening is shown neither in the type nor in the other illustrations cited, though Dr. Till [1] apparently lays stress on it.

The suture-line of the type is slightly more complicated than the one here reproduced (Fig. 1*c*), as is also that given by Neumayr, and especially the saddles are slenderer. This difference, however, is accounted for by the different size of the specimens. Neumayr's figure, on the other hand, shows exactly the same endings of the saddles as far as the third auxiliary.

The bundling of the striæ seems to become more pronounced in the larger specimens only, but the fact that the ornament is worn in the specimen under consideration gives it a certain resemblance to *Phylloceras modestum* Tornquist [2] from the *Sonninia* beds of the Espinazito Pass. This form, however, is thinner, and has a larger umbilicus (9 per cent).

Horizon and Distribution.—Neumayr and Uhlig [3] stated that (down till 1892) *Phylloceras Kudernatschi* was known only from the Mediterranean Klaus beds = Lower Bathonian = zone of *Parkinsonia ferruginea*. But in some of the beds referred to this horizon, e.g. the hæmatite beds of Swinitza or the *Posidonomya alpina* beds of the Italian Alps, the *fusca* and even the *aspidoides* zones of the Bathonian seem to be represented in addition to the lower zone. Haug [4] records *Ph. Kudernatschi* from the Bajocian (zone of *Cosmoceras subfurcatum* = *niortensis* up to *zigzag* hemeræ probably) of the Basses-Alpes. The species has also been found in the Glarner Alps of Switzerland, near Hallstatt, Gosau, Vienna, etc., in Austria, in the Carpathians, in Sicily, and in the Caucasus.

Locality.—No. 19. From beside the coral limestone on the Mombasa pipe-line at mile $\frac{1}{2}^{2}$. (Single specimen.)

Phylloceras sp. indet. (Pl. V, Figs. 2*a–c*.)

Dimensions.—

Diameter	25 mm.	
Height of the last whorl	58	per cent of the diameter.
Thickness	42	,, ,, ,,
Umbilicus	4	,, ,, ,,

Description.—This specimen consists of a little over half a whorl (wholly septate); and it has been rolled, so that though fragments of the test remain there is no trace of the ornament. The ammonite is very similar in shape to the specimen above referred to *Phylloceras Kudernatschi*, but a little thicker (42 per cent instead of 38 per cent),

[1] "Amm. Fauna d. Kelloway v. Villány": Beitr. Pal. Geol. Öst.-Ung. vol. xxiv, pt. ii, 1911, p. 255.

[2] "D. Dogger a. Espinazito Pass": Pal. Abh. Dames, N.F., vol. iv, pt. ii, 1898, p. 29, pl. v (xviii), fig. 2.

[3] Op. cit., p. 33.

[4] "Les Chaines Subalpines, etc.": Bull. Service Carte Géol. France, iii, No. 21, 1891, p. 74.

and the periphery thus appears more rounded. The umbilicus is very small and deep, and the sides are regularly rounded into it.

The suture-line could only partly be drawn, and this portion is composite, taken from both the anterior and posterior ends of the specimen. Apart from the diphyllic external and two lateral saddles shown in Fig. 2*c*, there are three more diphyllic saddles; but the remainder of the suture-line, apparently consisting of three more saddles, cannot be clearly made out. The suture-line, then, differs from that of the above specimen chiefly in having a more complex and deeper external lobe and a more diphyllic first lateral saddle.

Observations.—There is great resemblance in the suture-line and appearance (of the smooth inner whorls) to the Callovian *Phylloceras subobtusiforme* Pompeckj [1] from Alaska. But this form is a little thicker, and apparently has an umbilical edge, since it is compared with *Phylloceras subobtusum* Kudernatsch and *Phylloceras Abichi* Uhlig. The fact that the ornament is not preserved prevents closer comparison with *Ph. isomorphum* Gemmellaro,[2] which has similar (but variable) dimensions. Also the suture-line of this form has slenderer saddles and folioles. Since, however, the suture-line of the earlier portion of the East African specimen shows, in this respect, greater resemblance to Gemmellaro's figure than the last suture-lines (a matter of preservation), this point is less significant than the larger umbilicus in the Sicilian species.

Phylloceras trifoliatum Neumayr,[3] from the Bajocian of the Carpathians, also comes close to the present form, but its suture-line is characterized by a triphyllic first lateral saddle. Vacek [4] stated that the specimen from San Vigilio (from which the suture-line given by Neumayr in Fig. 2 was taken) was not identical with the Hungarian *Ph. trifoliatum* and belonged to *Ph. chonomphalum* Vacek of a different group. This point seems to have escaped Prinz,[5] whose otherwise unconvincing divisions within the genus *Phylloceras* have not been adopted by the writer.[6] Of the Bajocian forms of *Phylloceras* described by Prinz, *Ph. baconicum* [7] is very near the present specimen, but its suture-line is more complex than the one here figured (though taken from a larger specimen).

The absence of constrictions and its general appearance

[1] "Jurafossil. aus Alaska": Verh. Russ. Kais. Mineral. Ges. St. Petersb., ser. II, vol. xxxviii, 1900, p. 247, pl. vii, fig. 1.

[2] *Faune Giur. & Lias.*, pt. i, 1872, p. 6, pl. i, fig. 1; pt. v, 1877, p. 130, pl. xix, fig. 16.

[3] "Jurastudien," ii: loc. cit., p. 309, pl. xii, figs. 2, 3.

[4] "Üb. Fauna Ool. Cap San Vigilio": Abh. k.k. R.A., Vienna, vol. xii, 1886, p. 69.

[5] "Die Fauna ält. Jurabild. N.O. Bakony": Mitt. Jahrb. Ungar. Geol. Anst., vol. xv, 1904, p. 40.

[6] Jullien's (C. R. somm. Soc. Géol. France, June 19, 1911) divisions and speculations on sexual dimorphism among *Phylloceras* also seem unfounded.

[7] Ib., p. 38, pl. xxvii, fig. 2.

characterize the specimen as a member of the group of *Ph. heterophyllum*, and it is probable that it belongs to the same lineage as, and is a near relative of, *Phylloceras Kudernatschi* Hauer.

Locality.—This specimen (No. 551) was found (isolated) to the west of the Mwachi River, about $\frac{1}{2}$.

Phylloceras cf. *Kunthi* Neumayr. (Pl. V, Fig. 3*a*–*c*.)

1871. *Phylloceras Kunthi* Neumayr, "Jurastudien," ii: loc. cit., p. 312, pl. xii, fig. 6; pl. xiii, fig. 1.
1905. *Ph.* n.sp. ind., Popovici-Hatzeg, "Les Céph. Jurass. Moy. Mt. Strunga": loc. cit., p. 11, pl. iv, fig. 8.
1910. *Ph.* cf. *Kunthi* (Neumayr), Till, "Amm. Fauna d. Kelloway v. Villány": loc. cit., p. 253.

Dimensions.—			
Diameter	. .	19 mm.	
Height of the last whorl	. .	59	per cent of the diameter.
Thickness	. .	36	,, ,, ,,
Umbilicus	. .	5	,, ,, ,,

Description.—This specimen is a wholly septate cast and has only a small portion of the test preserved, namely, on the periphery, near the beginning of the outer whorl. Here the ornament consists of distinct radial striæ (about eleven to the 2 mm. of test shown) after the manner of *Phylloceras Velledæ* Michelin sp. It is a little thinner than the two forms previously described; in its elongate elliptical section it more resembles that referred to *Ph. Kudernatschi*. The whorls show their greatest thickness about midway between the periphery and the umbilicus; the latter is narrow and deep.

The suture-lines are well exposed throughout the last whorl. Apart from the eight saddles shown in Fig. 3*c* there are three more saddles externally, and about seven saddles internally, making altogether about seventy elements. The external saddle shows branching of its terminal leaflets (after the manner of *Ph. serum* Oppel sp. and *Ph. semisulcatum* d'Orbigny sp.), and the first lateral saddle becomes triphyllic owing to the leaning over of its originally tetraphyllic summit to the ventral side. The three saddles following this are diphyllic, the next six monophyllic.

Observations.—The absence of constrictions and other points characterize this specimen as a form of the group of *Ph. heterophyllum*. Though in dimensions and whorl-shape it resembles the ammonite above referred to *Ph. Kudernatschi*, its complex suture-line distinguishes it at once from that species. The subdivision of the terminal leaflets of the external saddle, however, is indicated in Neumayr's figure of the suture-line of *Ph. Kudernatschi*,[1] though this subdivision is more reminiscent of *Ph. subobtusum* Kudernatsch and many forms of the group of *Ph. tatricum* Pusch.

The slender whorl-section of this specimen is not unlike that of

[1] Loc. cit., pl. xii, fig. 4*c*.

Ph. Kunthi Neumayr, but is more rounded, and therefore nearer to the form described as *Phylloceras* n.sp. ind. by Popovici-Hatzeg, and compared with *Ph. Kunthi*. The thickness of the adult *Ph. Kunthi* is only 28 per cent of the diameter, but the inner whorl of the type-figure at a diameter still more than three times that of the specimen here described shows this thickness already increased to 32 per cent. The suture-line of *Ph. Kunthi*, according to Neumayr, is distinguished from that of *Ph. Kudernatschi* by a tetraphyllic first lateral saddle and a larger number of lobes. Dr. Till [1] also states that the suture-line of the flatter "Callovian" *Ph. Kunthi* is distinguished from that of the thicker Bathonian *Ph. Kudernatschi* by more numerous and more indented elements. In the small specimen under examination the first lateral saddle does not, of course, attain the great complexity of that of Neumayr's figure. The flatness of the periphery on which Till insists is not shown on the inner whorls, and, probably like that in Neumayr's figure of *Ph. Kudernatschi*, is accidental. The present specimen, however, is not definitely identified with *Ph. Kunthi* on account of its immaturity.

The very compressed *Ph. perplanum* Prinz [2] seems to belong to the same group of forms, but apparently in all the Bajocian species of the *heterophyllum* group the suture-line has undivided terminal leaflets to the saddles. On the other hand, there is a likeness to the suture-line of *Ph. subobtusum* Kudernatsch,[3] though whorl-shape, ornament, and umbilical rim are very distinct in that species. The specimens figured as *Ph. subobtusum* by Popovici-Hatzeg,[4] however, agree much better with the East African specimen. Only the umbilicus is larger; and Popovici-Hatzeg also states that up to a diameter of 25 mm. the shell is perfectly smooth.

Till [5] also describes a *Ph.* aff. *plicatum* Neumayr from the Callovian of Villány. Neumayr's figure [6] (at a diameter of 58 mm.) shows a whorl thickness of 36 per cent, which agrees very well with that stated above for Professor Gregory's specimen. The absence of the test on the latter, however, prevents closer comparison; besides, *Ph. plicatum* is Argovian, though apart from Hungary it has also been recorded from the Callovian of the Maritime Alps and of the Swiss Jura.

Of later forms, *Ph. isotypum* Benecke,[7] a species of the *acanthicus* zone (but recorded from the *bimammatum* zone by Pompeckj [8]),

[1] Loc. cit., p. 252.
[2] Loc. cit., p. 38, pl. xxvii, figs. 3, 4.
[3] Loc. cit., 1852, pl. ii, figs. 1–3.
[4] Loc. cit., 1905, pl. ix, fig. 9 especially.
[5] Loc. cit., 1910, p. 254.
[6] Loc. cit., 1871, pl. xii, fig. 7 (inner whorl).
[7] "Üb. Trias u. Jura i. d. Südalpen": Geogn. Pal. Beitr., 1865, p. 184, pl. vii, figs. 1, 2.
[8] *Beitr. Revision Amm. Schwäb. Jura*, 1893, pt. i, p. 29.

is very near to the present specimen both in whorl-shape and suture-line. The latter also greatly resembles *Ph. Riazi* de Loriol [1] from the *Renggeri* marls. The very complicated suture-line of the latter, however (at equally small dimensions), is distinguished by a lesser number of elements.

Horizon and Distribution.—*Phylloceras Kunthi* is widely distributed in the Callovian of the Mediterranean region (Austrian Alps, Hungary, Sicily, Daghestan, and India). The type comes from the zone of *Macrocephalites macrocephalus*. Haug [2] records this species with *Ph. disputabile*, *Protetragonites tripartitum*, and other Bathonian fossils from Chaudon, Basses-Alpes, whereas the ammonites doubtfully referred to it by Waagen [3] and Neumayr et Uhlig [4] came from the *athleta* beds.

Locality.—No. 550/I, Mwachi River, Pipe-line Crossing. Found together with *Protetragonites* cf. *tripartitum* Raspail sp. and *Hecticoceras* sp. juv.

Phylloceras cf. *disputabile* Zittel. (Pl. V, Figs. 4*a–d*.)

1893. *Phylloceras disputabile* (Zittel) Pompeckj, loc. cit.: Revision, p. 32. See there for synonymy.

1905. ,, ,, (Zittel) Popovici-Hatzeg, loc. cit., p. 13, pl. ii, figs. 1–9, text-fig. 3 on p. 13, figs. 4 and 5 on p. 14.

Dimensions.—

Diameter	. .	? 28 mm.
Height of the last whorl	. .	? 55 per cent of the diameter.
Thickness	. .	? 30 ,, ,, ,,
Umbilicus	. .	? 14 ,, ,, ,,

Description.—This specimen consists of a whorl-fragment, about 27 mm. long, and the above measurements are based on the restoration of the complete shell given in Fig. 4*b*. The fragment is worn, and there is no trace of the shell-ornament left. The rounded umbilical edge is apparently preserved near the smaller end, and the sectional view, given in Fig. 4*c* (magnified two diameters), is drawn from this portion. Fig. 4*a* shows the (morphologically) left side of the specimen, which is poorly preserved, and does not show the constrictions. On the opposite side, represented in Fig. 4*b*, the two constrictions are present, but they become indistinct on the lateral area. The constrictions pass across the periphery with a slight forward bend, but the forward convexity at the side and the umbilical curve, indicated in the figure, are hardly distinct enough to warrant a definite description of their course. The sides of the

[1] "Étude sur les Moll. et brach. de l'Oxf. Inf. d. Jura Bern.": Mém. Soc. Pal. Suisse, vol. xxv, 1898, p. 110, pl. viii, figs. 8–12 and text-fig. 29 on p. 111.

[2] *Traité de Géologie*, vol. ii. fasc. 2, 1908, p. 1023.

[3] "Jurassic Fauna of Kutch": Pal. Indica, ser. ix, vol. i, 1873, p. 25, pl. v, fig. 2.

[4] Loc. cit., 1892, p. 33.

fragment are flattened, but gradually rounded off to the periphery, and very abruptly to the umbilicus; the greatest thickness of the whorl is at the umbilical edge. The small inclusion shown by the impression of the inner whorl indicates a fairly large umbilicus.

The suture-line is characterized by the slightly subdivided terminal folioles of the external saddle, and by an irregularly trifid first lateral saddle. The lateral elements are highly complicated, and both the saddles and their folioles are very slender.

Observations.—The slightly falcoid constrictions and complex suture-line characterize the specimen as belonging to the group of *Phylloceras Capitanei* (Catullo) Neumayr. There is great resemblance to the forms figured by Popovici-Hatzeg as *Ph. disputabile* Zittel, especially his smaller specimens; and the section given by that author (fig. 3 on p. 13) agrees very well at a similar diameter. On the other hand, the suture-line of the East African specimen is more complex and of the type of that of *Ph. Puschi* Oppel,[1] which according to Till[2] is often confused with *Ph. disputabile*. In d'Orbigny's specimen and in the examples referred to *Ph. Puschi* by Till, however, the umbilicus is only 6–7 per cent of the diameter. Petitclerc[3] united *Ph. Puschi* with *Ph. Lajouxense* de Loriol,[4] and the young of the latter species would agree with the specimen under consideration in the large umbilicus; but the suture-line is too simple in *Ph. Lajouxense*, the whorl section too inflated, and the constrictions (apparently) too straight.

The specimen of *Ph. disputabile* figured by Dacqué[5] from the Dogger of Pendambili (railway line from Dar-es-Salaam to Morogoro) differs from the present example both in suture-line and in its deep constrictions. According to Haug,[6] however, the deep constrictions and prominent bulges which characterize the typical figure of Kudernatsch's appear only on the larger whorls. The umbilicus also seems to close with age, for in a specimen of 210 mm. diameter, quoted by Pompeckj,[7] it amounts to only 5 per cent of the diameter.

There is a resemblance to the forms figured by Vacek[8] as *Phylloceras ultramontanum* Zittel, but in that group the constrictions are more angular on the lateral area, and the elements of the suture-line are very simple and plump. This latter character also distinguishes the specimen under consideration from *Ph. mediterraneum* Neumayr, which occurs in the *macrocephalus* beds of

[1] = *Ph. tatricum* (Pusch) in d'Orbigny, Ter. Jurass., pl. 180 (Oppel, *Pal. Mitt.*, 1863, p. 216).
[2] Loc. cit., 1910, p. 259.
[3] *La Faune du Callovien des Deux-Sèvres*, 1915, p. 89.
[4] "Études sur les Moll. et Brach. de l'Oxf. Inf. d. Jura Lédonien": Mém. Soc. Pal. Suisse, vol. xxvii, 1900, p. 11, pl. i, figs. 1, 2; pl. ii, fig. 1.
[5] Loc. cit., 1910, pl. v, figs. 3*a*, 3*b*.
[6] Loc. cit., 1891, pp. 70, 73.
[7] Loc. cit., Revision, 1893, p. 32.
[8] Loc. cit., 1886, pl. v, figs. 15–20.

India and Madagascar, though the writer found closely comparable ammonites in abundance in the Argovian beds of Jebel Zaghuan, Tunis.[1] The first lateral saddle is trifid in this species as in the East African specimen, but the simple folioles of the saddles represented in the figures of Popovici-Hatzeg [2] and Prinz [3] are quite different. On the other hand, it appears that, as in the case of *Ph. disputabile*, the many references to *Ph. mediterraneum* given in palæontological literature probably include a variety of evolute *Phylloceras* of the *ultramontanum* group,[4] and of the *Capitanei* group in the case of *Ph. disputabile*. It has already been mentioned that though the course of constrictions cannot accurately be determined, the specimen under consideration probably belongs to this *Capitanei* assemblage.

The rectangular section of the specimen here described might suggest connexion with the genus *Sowerbyceras*. The suture-line, however, is sufficiently distinct from that of this genus.

Horizon and Distribution.—*Phylloceras disputabile* is a Bathonian form, and occurs (generally associated with *Ph. Kudernatschi*, *Protetragonites tripartitum*, etc.) in the South of France, the Italian Alps, at Swinitza in Hungary, in the Carpathians, the Caucasus. It has also been recorded from the "Callovian" (zone of *M. macrocephalus*) of East Africa and India, and Haug [5] has it already in the Bajocian (zones of "*Sonninia*" *Romani* and "*Cosmoceras*" *subfurcatum*) of the South of France.

Locality.—No. 10, from the grey, otherwise unfossiliferous limestone beside the break-pressure tank, mile $\frac{11}{11}$ on the Montbasa pipeline (together with *Sowerbyceras* sp. aff. *tortisulcato* d'Orbigny sp.).

[1] "Jurassic Ammonites from Jebel Zaghuan". Q.J.G.S., vol. lxix, 1913, p. 561.

[2] Loc. cit., 1905, text-fig. 6 on p. 15.

[3] Loc. cit., 1904, pl. xxxvi, fig. 8.

[4] Hochstetter (loc. cit., p. 142) states that *Ph. mediterraneum* begins in the Klaus Beds and ranges into the Tithonian. This vertical range is unusually great for a species group, even of a *Phylloceras*.

[5] Loc. cit., pp. 70, 73.

(*To be continued.*)

On the Investigation of the Mechanical Constitution of Loose Arenaceous Sediments by the method of Elutriation, with special reference to the Thanet Beds of the Southern Side of the London Basin.

By Herbert Arthur Baker, M.Sc., F.G.S.

THE mechanical constitution of a detrital sedimentary deposit is the aggregate result of the operation of a complex suite of physical laws which govern transport of detrital material by, and its deposition from, water in motion. These physical laws have been elaborately investigated by many workers, and while much remains obscure, important conclusions have been achieved. The detailed examination of the mechanical constitution of the sediments of the geological column has been neglected, although a few pioneer workers have obtained notable results. Sediments of economic value have received attention, but in the realm of pure geology workers have been slow to take up the investigation. Accumulating results indicate, however, that geologists would do well to devote attention to this line of research. Distinctive results are being obtained from sediments, which, even though they may not lend themselves at the present time to complete interpretation, from the point of view of reconstruction of the conditions under which the said deposits were formed, nevertheless bid fair to provide the geologist with another weapon in his armoury. Fluviatile deposits have been found to possess a mechanical constitution distinct from that of estuarine sediments, and the latter are again clearly differentiated, mechanically, from purely marine formations. It may be remarked, too, that the nomenclature in current use applied to the loose sedimentary deposits lacks that element of scientific precision so desirable and necessary if proper progress is to be made. Such terms as " sand ", " clayey sand ", " sandy clay ", and " clay " are at present employed by different writers in different senses, and some system of classification which would give definiteness to the meaning of these and similar terms appears to be urgently called for. The only satisfactory basis for such a classification must be a quantitative one, depending upon mechanical analyses of sediments. When a sufficiently comprehensive collection of comparative data is available it should be a simple matter to devise an adequate scheme for the classification of the loose detrital sediments.

With regard to the classification into grades, according to size, of the material which is liable to occur in any one sediment, a scheme which gives good results in practice is in current use. It is as follows :—

> 2 mm. diameter			Gravel grade.
> 1 ,, < 2 ,,	Very coarse sand	Sand grade.	
> 0·5 ,, < 1 ,,	Coarse sand		
> 0·25 ,, < 0·5 ,,	Medium sand		
> 0·1 ,, < 0·25 ,,	Fine sand		
> 0·05 ,, < 0·1 ,,	Coarse silt	Silt grade.	
> 0·01 ,, < 0·05 ,,	Fine silt		
< 0·01 ,,			Clay grade.

Deposits consisting wholly of material of one or other of the grades specified above do not appear to occur in nature. Detrital sediments consist of a mixture of certain proportions by weight of many of the above grades, and it is the purpose of a mechanical analysis to determine the proportionate weights of the grades present in the sediment under examination. The allocation of a descriptive name to a sediment depends, usually, upon the presence in it of some one particular grade which occurs in sufficiently marked preponderance to influence the general character of the whole. But proportionality of the various grades is often of great importance in influencing the nature of a sediment, especially in the case of the finer arenaceous deposits. A sandy sediment may contain a percentage-weight of the clay grade, which, though small, is nevertheless enough to bring up the capillarity and water-capacity of the whole to a value sufficient to result in considerable binding-power. Such a sediment, when seen wet, in the field, would be liable to be termed "clay", although the same material, seen dry, in the laboratory, would probably be termed "sand". These points emphasize the need for a definite classification of sediments, based fundamentally upon the grades present and the proportionality by weight of these grades.

Early in 1919 the opportunity was afforded the present writer of undertaking, at the Imperial College of Science and Technology, a piece of work which he had long had in mind, namely, a study of the Lower London Tertiary strata of the southern side of the London Basin. The sediments to be dealt with being in the main arenaceous, it appeared likely that useful results would be afforded by detailed mechanical analyses. Professor P. G. H. Boswell had found such analytical data of much service in his study of various deposits (including the Lower London Tertiaries) in East Anglia, and had further shown the great value of such work upon sediments from the economic point of view. Accordingly much time was spent in carrying out a very large number of careful mechanical analyses, and the opportunity was taken of revising the methods of experiment in this connexion. From results obtained, the writer is convinced of the usefulness and importance of this line of work to geologists,

and hopes that it will receive the attention which it deserves at the hands of future workers.

It is proposed in the present paper to deal with some points connected with the revised methods of experiment in carrying out mechanical analyses, and to give, in outline, the main results arising from this side of the writer's investigations, so far as the Thanet Beds alone are concerned.

All the data were obtained by elutriating samples of the various sediments in glass tubes of a special shape, by means of upward currents of water at known speeds. Sifting, by means of meshes and sieves, was not resorted to for the following reasons: (1) The data obtained by the use of sieves are not truly comparable with results given by the employment of currents of water, owing to the different behaviour of the individual grains in the two cases. A grain may be considered as possessing three dimensions at right angles to each other, a maximum, a minimum, and an intermediate dimension. When placed on a sieve it is the intermediate dimension which decides whether the grain pass the sieve or not, since, if this permit, the grain will turn up on end and drop through the sieve. When buoyed up by a current of water the grain turns so as to expose its greatest cross-sectional area to the current, and consequently, in this case, the maximum dimension, as well as the intermediate one, is of large account in deciding whether the grain shall remain in the tube or be washed off. (2) Meshes and sieves, especially fine ones, are liable to be inaccurate. It is not easy to obtain a sieve of any specified gauge, and the apertures in any sieve, especially after a little wear and tear, show a serious variation among themselves. (3) Sieves are very liable to become clogged up. This frequently occurs during a sifting process, so that even after prolonged agitation of the sieves large amounts of fine material will yet remain entangled within the meshes of even coarse sieves.

Elutriation by Water Currents:[1] (1) Physical Basis of the Method.

When mineral grains are allowed to settle freely in a liquid they do so under the influence of gravity, but the rate of subsidence

[1] General accounts of the method of conducting elutriation experiments have been given by Crook and also by Boswell. For these and for other information concerning the process, consult the following:—

(1) Crook, Appendix to Hatch & Rastall, *Sedimentary Rocks*, London, 1913, p. 349.

(2) Boswell, *British Resources of Sands and Rocks used in Glass-making*, 2nd (complete) ed., London, Longmans, Green & Co., 1918.

(3) Boswell, *British Resources of Refractory Sands for Furnace and Foundry Purposes*, London, Taylor & Francis, 1918.

(4) Stadler, "Grading Analyses by Elutriation": Trans. Inst. Min. and Metall., xii, 1912–13, p. 686.

(5) Keilhack, *Lehrbuch der praktischen Geologie*, 1908, 2nd ed., Stuttgart.

(6) Ries, *Clays, their Occurrence, Properties, and Uses*, 2nd ed., New York, 1908.

of any specified grain is controlled by its size, specific gravity, and shape, as well as by the density and viscosity of the liquid in which it is subsiding. Experimental work has shown that the size or surface-area of the grains is the dominant controlling factor, and is of much more account than specific gravity in the case of small particles. Where the aggregation of grains consists largely of variously sized fragments of the same mineral, as, for example, in a quartz sand, the difference of "free-settling velocity" or "hydraulic value" of the grains affords a convenient means of classifying them according to size. Although increase of temperature diminishes both the density and the viscosity of the water which is sorting the grains it is possible to apply an appropriate correction to counterbalance these variations. The process of elutriating by means of currents of water is based upon the fundamental assumption (which is justified by results) that the final velocity of subsidence of a grain is that of the upward current of water which will just keep it in suspension. Laborious experimental work on the relation between diameter of grains and rate of free settling in water has been carried out in the case of the mineral quartz, and has yielded data upon which the elutriation process is based. Loose arenaceous sediments, being composed very largely of quartz grains, can be classified into grades down to, and below, material of ·01 mm. diameter, and if necessary up to about 12 mm. diameter, and in the separation of any specified grade the experimenter may make the minimum and maximum limits of size as narrow as he pleases.

From the purely mathematical point of view the problem of the subsidence of a small sphere in a fluid medium was investigated by Sir G. G. Stokes.

If a small particle, assumed spherical, of density ρ_1 and radius a fall through a fluid of density ρ and viscosity μ, and at rest, it will be accelerated at first. This acceleration is not, however, constant, but decreases with increasing speed, so that the particle, if afforded the opportunity, eventually moves uniformly with velocity

$$U = \frac{2}{9} \cdot \frac{\rho_1 - \rho}{\mu} \cdot g a^2.$$

If the particle is at the bottom of an elutriator tube and it encounters an upward current of water of velocity V, it will initially begin to move up with the water with the same velocity. But gravity will retard it, and it will suffer a negative acceleration. Consequently its speed will be reduced, and it will ultimately, if afforded the opportunity, move upward with velocity

$$V - U = V - \frac{2}{9} \cdot \frac{\rho_1 - \rho}{\mu} \cdot g a^2.$$

If $V = \frac{2}{9} \cdot \frac{\rho_1 - \rho}{\mu} \cdot g a^2$ the particle will cease to rise after the steady state has been attained.

If $V < \frac{2}{9} \cdot \frac{\rho_1 - \rho}{\mu} \cdot ga^2$ it will fall again, and so will not be washed off.

If $V > \frac{2}{9} \cdot \frac{\rho_1 - \rho}{\mu} \cdot ga^2$ the particle will be washed off.

Thus, the critical point at which washing off just ceases will be when

$$V = \frac{2}{9} \cdot \frac{\rho_1 - \rho}{\mu} \cdot ga^2.$$

For a spherical grain of a specified mineral, falling through a specified liquid at a specified temperature,

$$\frac{2}{9} \cdot \frac{\rho_1 - \rho}{\mu} \cdot g = \text{a constant},$$

consequently we have

$$V = kD^2,$$

where V is the upward velocity of the water current,
k is a constant, and
D is the diameter of the grain.

This is known as the law of Viscous Resistance. R. H. Richards,[1] experimenting on ordinary quartz grains, considered this law to hold approximately for grains not exceeding about ·2 mm. diameter. The character of Richards' results suggests, however, that he made no allowance for temperature changes in the water in which the grains were subsiding. (See plot of Richards' results, Fig. 1.) In the light of later research work by another investigator it is now known that the law of viscous resistance does not hold closely for even small grains.

For larger particles and greater velocities it has been suggested that the rate of subsidence might conform to the law

$$R = kV^2$$

where R is the resistance to motion and k is a constant.

This was suggested by Newton, and hence the law is sometimes referred to as Newton's Law of Eddying Resistance. In the case where dynamic equilibrium exists between the particle and the liquid resisting its subsidence, R is just equal to the effective weight of the particle in the liquid. Rittinger considered that the formula

$$V = C\sqrt{D(\delta - 1)}$$

where C is a constant,
D is diameter of mineral grain, and
δ is specific gravity of mineral,
was applicable to the case of mineral grains settling in water. Richards found that Rittinger's formula held with tolerable accuracy for grains exceeding 1·55 mm. diameter, but below this limit the value of Rittinger's C decreased rapidly.

[1] Richards, *Textbook of Ore Dressing*, 1909, pp. 262-76.

Hence, for grains of a specified mineral, exceeding about 1·55 mm. diameter, subsiding in water at constant temperature, we have

$$V = k\sqrt{D} \text{ where } k \text{ is a constant.}$$

Richards found that this Law of Eddying Resistance is more nearly true the greater the velocity; that is, when the true viscous resistance plays a continuously less important part, and the eddying resistance an increasingly important part. If we take the value for the constant k as indicated by Richards' work, we find that the velocities calculated from the formula for grains between ·2 and ·5 mm. diameter are too great. In the plot shown on the graph (see Fig. 1) of the Law of Eddying Resistance the related values

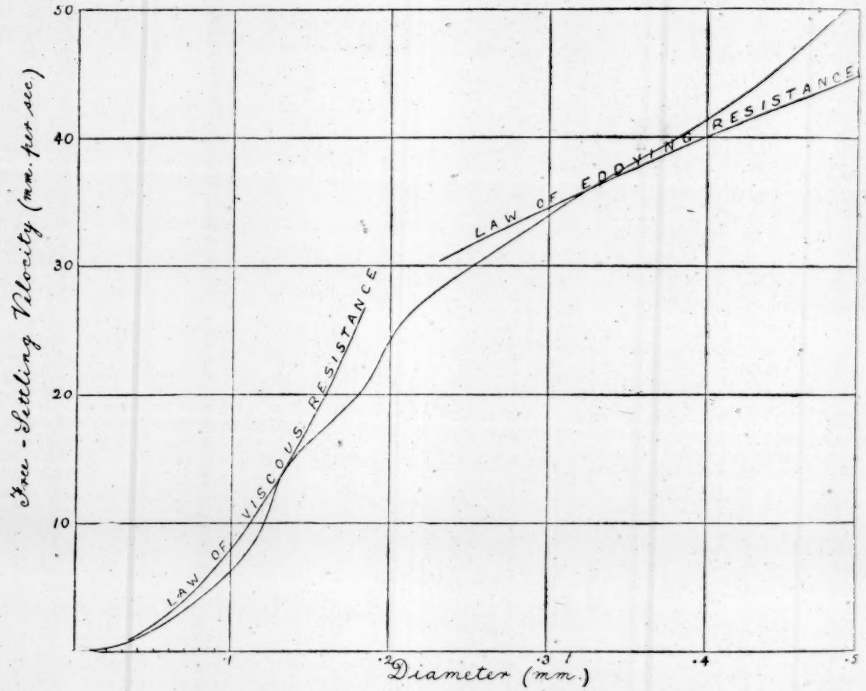


FIG. 1.—Plot of Richards' data on the free-settling velocities in water of quartz grains less than ·5 mm. diameter. With plots of the laws of viscous and eddying resistance inserted for comparison.

assumed for the purpose of determining k were ·327 mm. for D and 36·12 mm. per second for V, for the temperature of 15° C., other independent work having indicated the reliability of these figures. Even with the introduction of this modification of Richards' k it can be seen from Fig. 1 that Richards' results, for grains between about ·2 mm. and ·5 mm. diameter, do not agree closely with this theoretical law of eddying resistance.

In elutriation work on arenaceous sediments it is important for the investigator to know accurately the rate of settling of quartz grains between the limits of ·01 mm. and about ·4 mm. diameter. This matter has recently been made the subject of careful investigation by another worker, who very kindly permitted the present writer to make use of his results (which are as yet unpublished) in the carrying-out of mechanical analyses. It is not fitting to discuss here the unpublished work of another, but the writer may, perhaps, be permitted to state that the behaviour of subsiding grains, between the limits of ·2 mm. and ·5 mm. diameter, shows no closer adherence to the law of eddying resistance than does that of grains between the limits of ·01 mm. and ·2 mm. diameter to the law of viscous resistance. In fact, the rates of subsidence of grains between the limits of ·01 mm. and ·4 mm. diameter vary in a definite way, which is very clearly a compromise between these two laws.

In the absence of published information concerning this later research, which is of fundamental importance to workers interested in the mechanical analysis of sediments, it may be remarked that the data are of such a character as to lend themselves to mathematical expression in the form of formulæ. A series of formulæ, by means of which the rate of subsidence in water of a quartz grain can be calculated, when the diameter of the grain and the temperature of the water are known, has been worked out by the present writer, who hopes, at a later stage, to collaborate with the author of the research in discussing this point.

(2) Conduct of Elutriation Experiments.

The reasons for rejecting the rapidly working, two-tubed Crook elutriator in favour of the more tedious Schoëne single-tube process may be stated. The Crook elutriator possesses the advantage of effecting the separation of a sample into three grades in one operation. The disadvantages, however, far outweigh this initial gain. The Crook elutriator consists of a pair of tubes, one below the other, the water passing from the lower, smaller tube to the upper, wide tube, and thence escaping from the jet-tube carried by the latter. The diameters of the two tubes are adjusted to each other and to the water-supply in such a way that the total sand-grade (>·1 mm.) in the sample under examination is retained in the lower tube, the total silt grade (0·01 to 0·1 mm.) is retained in the upper tube, and the clay grade (<·01 mm.) is washed away. A practical difficulty which meets one at the outset is the matter of adjusting the diameters of the two tubes so as to preserve the correct ratio between them. It is only by chance that tubes of precisely the diameters required can be secured, and in the Crook elutriator, as set up in laboratories, the adjustment is usually more or less approximate.

The flow of a liquid through a tube is either of the steady, irrotational type, in which the liquid is moving in cylindrical layers coaxial with the axis of the tube, and the layer of liquid against the wall of the tube is at rest, or of the rotational, eddying type, in which the velocity of the current is more or less uniform over a large part of the cross section of the tube. To obtain the first type of flow certain preliminary precautions must be taken, but in the case of the current of water passing through an elutriator these precautions are ignored, so that we have to deal with the case of eddying flow. The tube wall has an important retarding effect upon the current, and the ratio of the circumference of a tube to its cross section varies inversely as the diameter. Osborne Reynolds has stated that the critical mean velocity at which the steady type of flow breaks up and is replaced by eddying flow varies inversely as the diameter of the tube. Hence, with so narrow a tube as the smaller tube of a Crook elutriator there is a much stronger tendency for the flow to approximate to the steady, irrotational type than in the case of a fairly wide tube. For the steady, irrotational type of flow the formula

$$v = \frac{2Q}{\pi a^4}(a^2 - r^2) \text{ applies}$$

where v = velocity at a point distant r from axis of tube,
Q = volume passing a cross section of the tube in unit time (or outflowing from jet in unit time),
a = radius of tube.

In the centre of the tube $r = o$, consequently

$$v = \frac{2Q}{\pi a^2}$$

and since $\frac{Q}{\pi a^2}$ is the average velocity of the current, as calculated from the outflow from the jet, it follows that, in the centre of the tube the velocity of the current is *twice* as fast as the calculated average. Therefore, in the smaller tube of a Crook elutriator, although the conditions requisite for steady, irrotational flow are not completely realized, the velocity of the current in the centre of the tube is approaching double the value of the mean speed for which the apparatus has been adjusted. Hence much material will be washed off which should be retained within the tube, and a mechanical analysis, effected by means of a Crook elutriator, will always give too low a percentage weight for the sand grade, and too high a percentage weight for the silt grade. The seriousness of the error involved is seen at once from the following comparative results, which are selected from a number of tests made by the writer :—

	Clay.	Silt.		Sand.			
	mm. <·01	mm. >·01 <·05	mm. >·05 <·1	mm. >·1 <·125	mm. >·125 <·15	mm. >·15	
	% wt.	% wt.	% wt.	% wt.	% wt.	% wt.	
Thanet Sand (upper part), Knee Hill, Abbey Wood.	5·64	2·37	12·10	37·00	39·67	3·22	By single-tube method.
		14·47		79·89			
	5·23	38·72		56·05			By Crook elutriator.
Woolwich Beds (basement loam), Charlton Pit.	26·20	11·07	12·17	33·07	15·85	1·64	By single-tube method.
		23·24		50·56			
	26·45	29·15		44·40			By Crook elutriator.

If the lower tube of the Crook elutriator were increased in diameter the upper tube would assume very unwieldy proportions.

Two other disadvantages of the Crook elutriator may be mentioned. The sample is separated into three grades only. Consequently, when the attempt is made to express the result of a mechanical analysis graphically, by means of a curve, the data are insufficient. Further, the elutriation curves of arenaceous sediments are now known to be of such a character that, for the purpose of obtaining accurate and reliable curves, grade divisions are required to be effected at points which this apparatus does not determine. In attempting to overcome this by employing more than two tubes, the original difficulty of adjusting the required tube-diameters correctly becomes insurmountable. In addition, it is not possible, when using a Crook elutriator, to apply a correction for, or make any adjustment to counteract, changes of temperature in the water passing through the apparatus, although this can readily be done when the single-tube method is employed. The temperature correction is a large one, and the ignoring of it is liable to lead to serious error, particularly in the case of the finer sediments.

The mechanical analyses made by the writer were carried out on samples of about 40 grammes weight, preliminary trials having shown this quantity of sediment to be well suited to the capacities of the tubes employed. The latter ranged in diameter from about 3·75 inches down to about 1 inch. Bearing in mind the value of graphical representations of the analyses obtained, preliminary experiments were made in order to ascertain the general character of the curves given by arenaceous sediments, so that the separations might be effected at points where the latter were most required for curve-plotting purposes.

The elutriator tubes employed by the writer are fitted with specially

made glass stoppers, which are ground so as to fit well, and always to enter the tube to the same depth. The stopper carries two short tubes, to one of which is attached the jet-tube and to the other the manometer-tube, carrying a graduated scale, intended for use with a particular jet. By having corresponding pairs of jets and graduated manometer-tubes, the same elutriator-tube may be used repeatedly in carrying out different parts of the mechanical analysis. In setting up the apparatus for the first time a jet and ungraduated manometer-tube are attached, and the water turned on. The flow is controlled by means of the screw-clip on the fairly thick-walled rubber connexion attached to the lower end of the elutriator-tube. With the water standing at some arbitrary point low down in the manometer-tube, the outflow, in cubic centimetres per minute from the jet, is determined by means of graduated measure and chronometer. This point is marked and the current then increased, so that the water stands at a higher point in the manometer-tube, when a fresh determination of the outflow per minute is made. Proceeding in this way a series of readings is obtained, which when plotted on a graph are found to lie on a smooth curve, by means of which the manometer scale can be constructed. This scale, therefore, indicates from the height of the water in the manometer-tube, the volume in cubic centimetres per minute flowing through the elutriator when the appropriate jet is being used.

A graph is constructed, showing for each elutriator-tube in use the relation between the rate of outflow from the jet, in cubic centimetres per minute, and the mean rate of the upward current in the tube in millimetres per second. The graphs for all the tubes can be conveniently represented on the same diagram—they are, of course, straight lines.

In proceeding to make a separation of a sample at some specified limit of diameter, the first step is to take the temperature of the water which is to be used. Knowing this, the appropriate rate of current is next ascertained. Then, on consulting the graph for the elutriator-tube which it is proposed to use, the rate of outflow from the jet required to give this current is readily obtained. It then only remains to select a suitable jet and corresponding graduated manometer-tube for attachment to the apparatus.

The separation of a sediment into a large number of grades is a tedious business, and much valuable time is often lost in removing from the elutriator, drying, and weighing the successive remainders as grade after grade is washed off the sample. In order to facilitate the progress of the analysis the writer has devised the following method of procedure which obviates the necessity of removing and drying the material at the completion of each stage of the process. It is necessary to know at the outset the weight of the empty elutriator-tube together with its rubber connexion and screw-clip at the bottom, but without the stopper and its adjuncts. A weighing is taken before the elutriation is commenced, of tube and contents,

when the sample is in the tube and the remainder of the tube is filled with water up to the level to which the bottom of the stopper reaches. The weighing can conveniently be obtained by means of a large specific gravity balance having one of the pans at a higher level than the other and equipped with a hook underneath. After the elutriation another weighing of tube and contents is taken, and the next stage in the analysis can be proceeded with immediately, whilst the weight of sediment remaining in the tube at the end of the previous stage is being calculated. This required weight is calculated from a formula which is obtained as follows :—

Before elutriation { Let weight of sediment in tube $= a$ gms.
Let weight of water in tube $= b$,,

After elutriation { Let weight of sediment in tube $= c$,,
Let weight of water in tube $= d$,,

a is known when put in, and total weight of contents is found, hence b = total weight contents $- a$.

The total weight $c + d$ is found by weighing.

Put $c + d = x$; then $d = x - c$.

Now the total volume of sediment and water remains the same at the end of the experiment as it was at the beginning.

Put ρ_1 = density of water used, and
ρ_2 = density of sediment.

Take $\rho_2 = 2{\cdot}65$ (treating the sediment as a pure quartz sand).

Then volume before elutriation $= \dfrac{a}{2{\cdot}65} + \dfrac{b}{\rho_1}$ cu. cm.

and volume after elutriation $= \dfrac{c}{2{\cdot}65} + \dfrac{d}{\rho_1}$ cu. cm.

$$\therefore \quad \frac{a}{2{\cdot}65} + \frac{b}{\rho_1} = \frac{c}{2{\cdot}65} + \frac{d}{\rho_1}$$

i.e. $a\rho_1 + 2{\cdot}65b = c\rho_1 + 2{\cdot}65d$,

and substituting $x - c$ for d, we get

$$a\rho_1 + 2{\cdot}65b = c\rho_1 + 2{\cdot}65x - 2{\cdot}65c.$$

Hence $$c = \frac{2{\cdot}65\,(x - b) - a\rho_1}{2{\cdot}65 - \rho_1}$$

The formula gives very good results, since a, x, and b are all determined by weighing, and the error involved by taking the density of the sediment as 2·65 is very small, since arenaceous sediments are very largely quartzose. For the value of ρ_1 appropriate to the temperature of the water at the time of the experiment, it is convenient to consult a graph showing the variation of the density of the water in use with change of temperature. This graph can be constructed from the results of preliminary experiments on the water. It may be remarked, however, that an error in the determination of ρ_1 considerably greater than the experimenter is likely to make in practice, introduces only an insignificant error into the final evaluation of c. It is well, however, to be as accurate as possible,

since errors in the determination of c are accumulative, the c of one stage of the analysis becoming the a of the next.

In the earlier stages of an analysis, when washing off the very finest material, the method outlined above is not practicable. Wide and heavy tubes, such as cannot be suspended from the arm of a laboratory balance, are usually then in use. Moreover, much of the material removed consists of clay or lithomarge, hydrated silicate of alumina, and consequently the figure 2·65 for its density is inadmissible. The writer determined the mean densities of a number of Lower Tertiary sands of different types, and found that in sand containing a fair percentage-weight of the clay grade the average density dropped rather markedly. A quartz sand containing 4 per cent by weight of clay has an average density of 2·60, and the average density decreases below this figure at about ·0015 for every 1 per cent weight increase of the clay grade. A quartz sand with 20 per cent by weight of clay has an average density of 2·574. The Lower Tertiary sands, when washed free from clay, had the same density as quartz (2·65).

Another method, which avoids loss of time in the drying of residues, is as follows: On the completion of a stage of the elutriation process the residue is run out from the tube into a glass flask filled to a mark on the neck with water. The weight of water required to fill the flask to the mark is known. When the sediment is in the flask the water displaced by it is removed, so that the water stands at the mark once more. A weighing is then taken. The difference between weight of sediment with water to mark and weight of water to mark gives the weight of the sediment *in water*. The weight of this sediment, when dry, is then calculated from the formula:—

$$\text{Weight (gms.)} = \frac{d}{d-1} \times \text{weight in water (gms.)}$$

where d = density of the material.

As already stated, if the clay material has been removed from the sample, the density of arenaceous deposits may safely be taken as 2·65. The above formula assumes the density of the water to be 1, but the error involved is negligible in practice.

This method is particularly useful when elutriating arenaceous sediments after the clayey material has been removed. It is then very convenient to calculate the initial weight of sediment from the formula given above. If an initial weight of 40·15 gm. be taken this will weigh exactly 25 gm. in water, and the successive weights in water obtained afterwards have only to be multiplied by four in order to give percentages.

(*To be continued.*)

REVIEWS.

GEOLOGY OF THE YANGTSE ESTUARY BELOW WUHU. By V. K. TING. Whangpoo Conservancy Board. Shanghai Harbour Investigation, Series 1, No. 1. pp. 84. Shanghai, 1919.

THIS work is divided into four sections, dealing with (1) stratigraphy, (2) structural geology, (3) physiography, and (4) history of the Yangtse Estuary.

The greater number of the deposits are Palæozoic, the earliest fossiliferous beds having yielded an Ordovician fauna. These are succeeded by quartzites doubtfully referred to the Devonian system. The Carboniferous is divided into Lower and Upper Carboniferous Limestones, with Middle Carboniferous containing the Nankao Coal series between. The Lungtan Coal series is referred to the Permian, and a succeeding limestone to the Permian or Triassic system. No undoubted Mesozoic rocks have been determined in the area, though the strata of another coal-bearing group at no great distance away have yielded a fossil flora thought to be undoubtedly of Rhætic age. The next deposit in order of age is the Tat'ung conglomerate of Tertiary age, concerning the formation of which there is a difference of opinion. The question is discussed by the author. Upon this conglomerate reposes loess, which is the newest deposit except the alluvium.

An account of the igneous rocks includes descriptions of granites, intrusive porphyritic rocks, rhyolitic and trachytic lavas, and basalts.

The structural section deals with the tectonics of the region. A general account of the physiography follows. The historical sketch treats of the question of the theory of ancient mouths of the Yangtse, the growth of its delta in historic times, and the origin of the Whangpoo River.

The area forms part of the ground traversed by Richthofen, whose work is recorded, but much that is new is added, and some of Richthofen's views are criticized.

The work is illustrated by a coloured folding map of the geology, many other geological maps and sections, and photographic illustrations, and is a valuable description of an area by an up-to-date geologist.

The work was undertaken for a specific purpose, the investigation of the hydrography of the Yangtse Estuary. We look forward to the production of important geological memoirs of other areas by Mr. Ting (who is Director of the Government Geological Survey) and his assistant surveyors.

J. E. M.

Diagnostic Characteristics of Marine Clastics. By E. M. Kindle. Bull. Geol. Soc America, vol. xxviii, pp. 905–16. 1917.

THE author of this paper is very deeply and rightly impressed with the truth of the saying that " the present is the key to the past ". He therefore brings forward some of his observations of phenomena in present-day sediments which may be of use in deciding whether rocks are of marine or freshwater origin. The points considered are (1) the behaviour of fine sediment in fresh and salt water, (2) the surface markings and textures developed during sedimentation and during desiccation of muds, and (3) the distinguishing characters of ripple-marks. In the first place it is noticed that alternating layers of sandy and muddy material deposited in salt water have more sharply defined boundaries than those laid down in fresh water, owing to the comparatively rapid flocculation of very fine sediment in salt water.

Passing to the second section, it is explained that this flocculation of clay is accompanied by small vertical currents, and that these cause structures known as " pit and mound structures " on the surface of the deposit. Structures produced during desiccation are also different in freshwater and salt-water muds ; the " sun cracks " of salt-water muds have level or turned down edges, while the edges of these cracks formed in freshwater muds are turned up. Further, the texture of a dried saline mud is vesicular, and thus quite unlike that of a freshwater mud. The question of ripple-marks is discussed at some length, and the author draws distinctions between those due to current action and those due to wave action without forward movement. The former type will be found to predominate in tidal seas, while the latter is more prevalent in inland lakes ; it is also noted that the ripple-marks produced by rivers will show evidence of motion in one direction only, while those due to tidal currents will indicate motion in at least two opposite directions. Though in the opinion of the reviewer the author appears to be somewhat over-sanguine, yet the points advanced in this paper seem to be worthy of serious consideration when working through series of sediments of doubtful origin.

W. H. W.

The Mineral Deposits of South America. By B. L. Miller and J. T. Singewald, jun. pp. ix + 598, with 61 figures. New York : McGraw-Hill Book Co., Inc. London : Hill Publishing Co., Ltd. 1919. Price 25*s*.

WE cordially welcome this book, inasmuch as it gives us for the first time a collected and accessible account of the great mineral wealth of the South American Continent, from which came so much of the fabled wealth of the Spanish galleons. The amount of detailed

information contained in these pages is astonishing, and though written in somewhat more prosaic style than the stories of the early adventurers, it is equally interesting, perhaps more so to an economic geologist, since the romance is here founded on fact.

The first chapter contains an admirable description of the general physiographical and geological features of South America, with a discussion of tectonics and their bearing on the problems of mineralization. The country is divided into eight districts—the Guianan Highlands, the Brazilian Highlands, the Cordilleras, the Llanos and the plains of the Orinoco, the plains of the Amazon, the plains of the Paraguay and Paraná, the Pâtagonian Pampas, and the coastal plains. Nearly all the economic minerals are contained in the first three.

Each of the succeeding eleven chapters contains a full and comprehensive account of the economic geology of one of the South American States, a large part of the information being the result of personal observations by the authors, especially in Brazil, Chile, Bolivia, and Peru, and in part in Argentina, Ecuador, and Uruguay. Each chapter closes with an admirable bibliography, which in some cases include over 200 items. This is an invaluable feature of the book.

Among so many points of interest it is difficult to make a selection for special mention. One of the most fascinating chapters is that on Bolivia, where the rich silver-tin-tungsten mineralization naturally comes in for a large share of attention, both on account of its intrinsic value and for its theoretical significance. It is refreshing to read a clear and coherent account of these important deposits as they really are, freed from the absurd generalizations of the Freiberg school. The Bolivian silver-tin deposits seem to form a well-authenticated example of the occurrence of tin and tungsten in quantity in connexion with Tertiary igneous activity. It is noteworthy, however, that as soon as the frontier of Argentina is crossed the minerals are clearly associated with Palæozoic granites. Hence we have here an instance of the occurrence of a similar type of mineralization in two neighbouring areas at two widely separated periods of time. It is as yet too early to say definitely whether there is any overlap of these two mineralizations in space.

A very full account is given of the iron and manganese resources of Brazil; the former are undoubtedly enormous, some good authorities having estimated the reserves of hæmatite in the State of Minas Geraes alone at 12,000,000,000 tons. This is probably excessive, but it is clear that Brazil contains the most important undeveloped deposits of iron-ore of any country in the world. However, development is hindered by difficulties of transport, owing largely to the absence of important coalfields and the remoteness of the iron districts from the coast. The magnetite ores of Jacupiranga, described by Derby, are of great petrographic interest, since they are